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BLAST CHARACTERISTICS OF 20 and 100 TON HEMISPHERICAL AN/FO CHARGES, NOL DATA REPORT

By
L. D. Sadwin
M. M. Swisdak, Jr.

17 MARCH 1970

NOL

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

ATTENTION

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BLAST CHARACTERISTICS OF 20 and 100 TON HEMISPHERICAL AN/FO CHARGES, NOL DATA REPORT

Prepared by:
L. D. Sadwin
M. M. Swisdak, Jr.

ABSTRACT: Two twenty-ton and one 100-ton hemispherical AN/FO (ammonium nitrate/fuel oil) charges were detonated on the surface at the Defence Research Establishment Suffield, Ralston, Alberta, Canada. The tests were conducted during August 1969 as a cooperative U.S./Canadian effort.

The major results were:

1. AN/FO has been demonstrated to be a highly suitable explosion source for nuclear airblast simulation.

2. Over the 1-200 psi region, there was no significant difference in the pressure-distance characteristics between AN/FO and TNT.

3. The impulse characteristics of the AN/FO system were found to be slightly lower than those of TNT.

4. No self heating of AN/FO was observed.

5. Conventional cube root scaling applies for AN/FO over a 10^3 range in explosive weight, once a charge weight of 200 pounds is exceeded.

AIR/GROUND EXPLOSIONS DIVISION
EXPLOSIONS RESEARCH DEPARTMENT
U. S. NAVAL ORDNANCE LABORATORY
White Oak, Silver Spring, Maryland

NOLTR 70-32 **17 March 1970**

Blast Characteristics of 20 and 100 Ton Hemispherical AN/FO Charges, NOL Data Report

This is a data report which presents the results of the Naval Ordnance Laboratory (NOL) blast measurements on the recently completed AN/FO tests. AN/FO is an explosive mixture of ammonium nitrate and fuel oil. It is being developed as a TNT replacement for large scale nuclear airblast simulation.

The tests were conducted in cooperation with the Defence Research Establishment Suffield, at Ralston, Alberta, Canada, during August 1969. Several other U. S. agencies also participated in this program.

This effort was funded by the Defense Atomic Support Agency through the Naval Ships Engineering Center of the Naval Ship Systems Command. The work was performed under DASA Subtask NA 007-04, Task NOL-194.

The use of company names throughout this report is for technical information purposes only. No endorsement or criticism is intended.

GEORGE G. BALL
Captain, USN
Commander

J. PETES
By direction

NOMENCLATURE

A, B, C, D, E	= coefficients of gage calibration fit (Equation (B-1))
Δf	= frequency deviation , (Hz)
I	= positive impulse, (psi-msec)
P_o	= atmospheric pressure, (psi)
P	= peak side-on overpressure, (psi)
p	= instantaneous overpressure, (psi)
R	= distance, (feet)
T_o	= atmospheric temperature, (^oR)
t	= instantaneous time, (msec)
TOA	= shock time of arrival, (msec)
W	= charge weight, (pounds)
β	= time decay coefficient, (Equation (B-2))
α	= pressure decay coefficient (Equation (B-3))
λ	= scaled distance, (feet/pound$^{1/3}$)
τ	= positive duration, (msec)

SUBSCRIPTS AND SUPERSCRIPTS

0	= atmospheric conditions
1	= standard conditions, (14.7 psi, 519^{o}R)
2	= test site conditions
'	= parameter cube root scaled
m	= extrapolated parameter
ss	= secondary shock

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1. Introduction

1.1 Background

There is a continuing requirement for the development of a large scale field source for generating an airblast environment that simulates that of a nuclear explosion. The need arises from programs designed to test the vulnerability and blast hardness of military hardware and strategic structures. For example, as part of its ship blast-hardening program the Navy has exposed special structures e.g., radar masts, deck houses, and fully operational ships to particular blast environments.

Large scale simulation techniques with charge weights up to 500 tons, usually involve the use of chemical explosives. The explosive for such a source should be inexpensive, easily handled, and safe to use. In the past, multiton simulant charges have been constructed from cast TNT blocks. Some work has been done using balloons filled with detonable gases (ref. (1)).

During 1967, NOL proposed the use of ammonium nitrate/fuel oil (AN/FO), a commercial blasting agent, as a replacement for the TNT used in large blast trials. Among the expected advantages of the AN/FO system were:

1. Increased economy. AN/FO costs about seven cents per pound in place at ground zero compared to about 11¢ to $1.00 per pound for TNT in place--depending upon whether reclaimed or new TNT is used.

2. The availability of AN/FO in large quantities and at convenient locations; the TNT supply is limited and is greatly affected by munitions requirements.

3. Fewer blast anomalies (e.g., jetting and assymetrical blast fronts) would be expected from a homogeneous charge in contrast to the block-built TNT charges.

4. Improved safety. The ammonium nitrate and fuel oil are non-explosive until mixed. Fully mechanized mixing and delivery systems are already developed for charge preparation at ground zero.

After a pioneering effort conducted by NOL in Nevada during 1966 which establishe the detonability of unconfined AN/FO and which determined its airblast characteristics (ref. (2)), the way was paved for a larger scale study. In the fall of 1966 NOL proposed a program which culminated in these AN/FO trials of August 1969.

1.2 Objectives

The general objective of this program was to demonstrate the feasibility of using AN/FO as the explosion source in the Department of Defense's nuclear airblast-vulnerability and hardening program. This objective was an outgrowth of

the original intent to satisfy the more limited blast requirements for the Navy's airblast-ship hardening program.

A number of specific objectives were investigated by NOL and other participating agencies during the course of this effort. The major objective was to determine the airblast characteristics of AN/FO. Since some test structures were available from earlier tests at the site, a secondary objective was to measure their blast response.

The primary objectives were:

1. To verify the detonability, scaling, and reproducibility of AN/FO for charge weights up to 100 tons.

2. To extend existing AN/FO airblast pressure-time-distance data by including measurements from close to the charge surface out to the 1 psi level.

3. To study fireball growth and observe blast anomalies.

4. To study the engineering aspects of preparing and firing bagged and bulk AN/FO charges.

5. To compare the airblast performance of AN/FO with TNT.

6. To compare the blast characteristics of bagged and bulk 20 ton AN/FO hemispheres.

7. To determine the temperature stability of the AN/FO explosive prior to firing for charge weights up to 100 tons.

8. To study the cratering of 20 and 100 ton AN/FO hemispheres.

The secondary objectives were:

1. To blast load a full scale frame house at the 1.5 psi level from the 100 ton AN/FO test (Event III).

2. To blast load an underground model silo and buried rock inclusions on Event III.

This report deals with NOL's efforts on primary objectives 1, 2, 4, 5, 6, and 7. The other agencies participating on these trials will report their project results separately.

1.3 Experimental Program

The experimental phase of this program was carried out with the cooperation of the Defence Research Establishment Suffield (DRES), at Ralston, Alberta, Canada (ref. (3)). In addition to the field support they provided, DRES made shock time-of-arrival and crater measurements as well as high speed photographic observations on all three AN/FO tests. These data already have been reported in reference (4) and will be included in a comprehensive DASA report to be prepared by NOL covering all aspects of these AN/FO trials.

Other U. S. Agencies participating in these trials included the Ballistic Research Laboratories (BRL), Naval Civil Engineering Laboratory (NCEL), Naval Weapons Center (NWC) and the U. S. Geological Survey (USGS). BRL provided pressure measurements in the predicted 3000 to 30 psi overpressure range. NCEL made studies of the response of rock inclusions and made body motion observations of a model silo exposed to the blast loading of the 100 ton AN/FO test. NWC made observations on a two story frame house exposed at the 1.5 psi level from the 100 ton AN/FO test. The Geological Survey and DRES made crater studies. NOL was responsible for the explosives phase of these trials and made pressure measurements from 200 down to 1 psi.

The three tests conducted during the AN/FO trials at DRES during August 1969 were as follows:

EVENT I - 20 ton AN/FO hemisphere, bagged. Detonated 14 Aug 1969.

EVENT II - 20 ton AN/FO hemisphere, bulk in fiberglas shell. Detonated 21 Aug 1969.

EVENT III - 100 ton AN/FO hemisphere, bulk in fiberglas shell. Detonated 28 Aug 1969.

2. Experiment and Procedures

2.1 Test Site and Field Arrangement

The trials described in this report were conducted at the Watching Hill Blast Range of the Defence Research Establishment, Suffield, at Ralston, Alberta, Canada. Figure 1 shows the range area of DRES.

This site was selected for reasons of logistics and because it enabled direct comparisons to be made with the earlier work on detonations of multiton TNT hemispheres (ref. (5) and (6)). The physical characteristics of this site have been fully described in the Operation Prairie Flat Operations Plan (ref. (7)).

The general layout of the ground zeroes, NOL cable lines, bunkers and camera positions for all 3 events is illustrated in Figure 2. In order to accommodate the secondary objectives of these trials, the ground zero for Event III (100 tons of AN/FO) was selected so that the model silo, instrumented on an earlier MEST test, could be blast loaded again. The frame house 1700 feet northeast of GZ III was therefore exposed at the 1.5 psi level. This house was repaired after being exposed at the 1 psi level on Operation Prairie Flat. The ground zero for Events I and II were placed along a NE-SW line with GZII 300 feet from GZIII, and GZ's I and II being 160 feet apart.

NOL had 8 gage stations on each event, with 2 pressure gages at each station. (This instrumentation is described in Appendix A of this report). For Events I and I

the NOL gage line was perpendicular to the line between ground zeroes. This arrangement permitted an easy reorientation of the gages at each station without establishing new stations. The 200, 100, 50 and 20 psi gage stations were baffled flush with the ground. The 10, 5, 2 and 1 psi gage stations were above the surface and used disc type baffles. Photos of both types of gage stations are presented in Figure 3.

All gage cables were placed in a trench 12-18 inches deep. The cable trenches connected each gage station to a common NOL cable trench which ran to the NOL instrumentation trailer some 3000 feet distant.

Most of the ammonium nitrate for the AN/FO was delivered to the Suffield, Alberta, Canadian Pacific Railroad (CPR) siding in a 70 ton hopper car. The siding was about 35 miles from the test site. The remainder of the AN was trucked directly to the range in 22 ton capacity TRIMAC tanker trucks from the supplier in Calgary, Alberta.[1] Further details on charge construction are provided in Section 2.2 of this report.

2.2 Explosives and Charge Construction

2.2.1 AN/FO Main Charge

The main charge for these trials was a 94/6 by weight AN/FO mixture [94% ammonium nitrate and 6% fuel oil]. The AN itself was a commercial fertilizer and was basically the same type of prills[2] used in our 1968 Nevada tests (ref.(2)). The FO was summer grade No. 2 diesel fuel. A red dye was added to the fuel oil to permit a ready visual check on the AN/FO mixing proportions.

The 20 tons of bagged AN/FO for Event I were prepared at the GZ area. The AN was transported from the 70 ton hopper car at the Suffield CPR siding by the AN/FO mixing truck. The truck had a capacity of about 7 tons of mixed product (AN/FO). Thus, three loads were required per 20 ton event. A bagging unit[3] was

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[1]The explosives contractor to NOL was Ace Explosives Ltd of Calgary, Alberta. The AN used was manufactured by Cominco Ltd also of Calgary, Alberta.

[2]Prills are porous, spherical particles. They are formed by dropping molten AN in a prilling tower and are much like lead shot in size and shape. They have a density of about 1.4 gm/cc compared to the crystal density of AN which is 1.725 gm/cc.

[3]The bagging unit was designed and built by Mr. G. R. Rintoul of Ace Explosives, Ltd.

located at the site during Event I charge placement. The arrangement of the mixer truck and bagging unit at the GZ location is shown in Figure 4.

A total of 800-50 pound bags was prepared for this first 20 ton charge. Six hun dred and fifty 50-lb bags were used in the layered arrangement illustrated in Figure Loose AN/FO from 150 of the bags was poured into the spaces between bags to form a charge with uniform density, i. e., no airspaces. The bag dimensions were 21 x 13.5 x 5.8 inches.

The AN/FO mixer truck used a system of augers to feed the AN from the bins to the fuel metering point. At this point the red-dyed fuel oil was mixed with the AN. The mixed AN/FO was then fed through a vertical auger and out a swinging horizontal auger to place the AN/FO where it was needed, i.e., into the bagging unit for Event I and into the charge cases for Events II and III.

Changes in the fuel oil content of the AN/FO were detected very quickly by visual means because of the red-dyed fuel oil used. The fuel oil content was also monitored quantitatively throughout the explosives placement operation by chemical analysis (ref. (9)). Table 1 contains data on AN/FO charge dimensions, weight, density and fuel content for all three events.

Events II and III were charges of bulk AN/FO placed into thin walled fiberglas / polyester resin containers. The fiberglas/polyester resin shell[1] was made of section having full compound spherical curvature.

The 20 ton size container for Event II was 14.0 feet in base diameter and was made of 11 sections each 3/16 inch thick[2]. The 100 ton size container was 24.2 feet in base diameter and had 22 sections, each 1/4 inch thick . The sections were joined together by nyl(bolts and epoxy resin adhesive.

To fill the fiberglas shells the mixer truck was backed up to the container for AN/FO placement. The time required for each mixing and placement cycle (i.e., each 7 tons of AN/FO) was about three hours. To reduce the loading time on the 100 ton AN/FO charge most of the AN was trucked from the Cominco fertilizer plant in Calgary to the GZ via 22 ton capacity TRIMAC tanker trucks. The AN was

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[1] The sections for the two containers were manufactured by Rogay Models of Bethesda, Maryland.

[2] Before the field operation, we conducted high speed camera tests on samples of the shell material to determine their behavior when in contact with detonating explosives. The high speed photographs indicated break-up of the fiberglas within a few inches of the charge.

fed into the mixer truck and the AN/FO into the container in a continuous operation. Using this loading system, about 23 tons of AN/FO were mixed and placed in a four hour period. A photograph illustrating the arrangement of the TRIMAC tanker and AN/FO mixer trucks at the 100 ton GZ is presented in Figure 6. The completed 20 ton and 100 ton bulk AN/FO charges are shown in Figures 7 and 8.

2.2.2 Booster and Primacord Initiation Method

The hemispherical boosters used for all three events were prepared by the U. S. Naval Ammunition Depot, Hawthorne, Nevada (ref. (8)). The boosters were a nominal 250 pounds each total weight and consisted of a 16 pound hemispherical 50/50 pentolite primer with about 234 pounds of TNT cast over it.

NOL developed a primacord initiation method (ref. (2)) which was used for each event. In this method a strand of 100 grains per foot primacord is placed in a shallow, radial trench beneath the charge, leading from the GZ to beyond the outer edge of the AN/FO charge. The GZ end of the primacord is fed through a radial hole in the booster and a small knot is tied at the top to secure it. This method greatly simplified the arming procedure, as the electric detonator is simply attached to the other end of the primacord still exposed after the charge has been completed. The explosive train is: electric detonator → primacord → pentolite primer → TNT booster → main charge (AN/FO). This is all illustrated schematically in Figure 9.

2.3 NOL Instrumentation

Airblast pressure histories were measured with variable reluctance transducers and recorded on magnetic tape recorders. The temperature within the AN/FO charge was monitored with thermistors on each event. The instrumentation system is described in detail in Appendix A.

Before each event, both the pressure gages and the thermistors were statically calibrated. The calibration of the thermistor took into account the resistance of the cable between ground zero and the instrumentation trailer.

2.4 Data Analysis Procedures

The pressure-time records were digitized and then analyzed using techniques which are described in detail in Appendix B. The parameters computed include peak pressure, positive duration and positive impulse. Extrapolations to peak pressure and positive duration were made using techniques described by Ethridge (ref.(10). These extrapolation techniques were used to take into account both the finite rise-time of the observed signal incurred because of instrumentation

system limitations and also any early-time gage malfunctions. Gage malfunctions were noted on several signals from each event--namely, at those stations in the 50 psi region and above. These malfunctions were manifested by a loss of FM carrier amplitude for several milliseconds upon the arrival of the airblast wave. This loss of carrier exhibited itself as spurious peaks on the discriminated signal. To handle this, only that portion of the record that occurred after the gage resumed normal operation was used in the computations.

A comparison between the procedure described in Appendix B for determining impulse and a direct measurement with a planimeter on several pressure-time records showed excellent agreement (within a few percent).

Time of arrival data were measured directly from the tape recordings, using an electronic counter operating in the time interval mode.

3. Airblast Results

3.1 The Data and Scaling Procedures

The unscaled data obtained on all three events are presented in Tables 2, 3, and 4. The data presented in these tables are for the ambient conditions at DRES as shown in Table 5. To make for a useful comparison with previously published TNT data (ref. (5) and (6)), the AN/FO data were cube root and Sachs' Scaled (ref. (11)) to standard sea-level conditions of pressure and temperature. To do this scaling, the following equations were used:

For Pressure:

$$P_1 = P_2\left(\frac{P_{01}}{P_{02}}\right), \tag{1}$$

For Distance:

$$\lambda = \frac{R}{W^{1/3}\left(\frac{P_{01}}{P_{02}}\right)^{1/3}}, \tag{2}$$

For Times:

$$\left.\begin{matrix} TOA_1' \\ \text{or} \\ \tau_1' \end{matrix}\right\} = \frac{\left\{\begin{matrix} TOA_2 \\ \text{or} \\ \tau_2 \end{matrix}\right\}}{W^{1/3}\left(\frac{P_{01}}{P_{02}}\right)^{1/3}\left(\frac{T_{01}}{T_{02}}\right)^{1/2}}, \tag{3}$$

And for Impulse:

$$I_1' = \frac{I_2}{W^{1/3}\left(\frac{P_{02}}{P_{01}}\right)^{2/3}\left(\frac{T_{01}}{T_{02}}\right)^{1/2}} . \qquad (4)$$

The scaling factors for all three events are presented in Table 5.

The data for each station of Tables 2, 3 and 4 were averaged and the scaling equations (Equations 1 through 4) were applied. The resulting scaled averaged data are presented in Tables 6, 7 and 8 for Events I, II and III respectively. All tabulated data are given to three significant figures.

The peak pressure versus scaled distance data (P_{1m} vs λ) for all three events are shown graphically in Figure 10. The TNT standard curve (ref. (5)) is also plotted in this figure to enable the making of direct comparisons between AN/FO and TNT.

A 5th degree polynomial was fitted to a composite of all of the pressure (P_{1m})-scaled distance (λ) data of Tables 6, 7 and 8. The form of the equation was:

$$\ln P_{1m} = 10.4781 - 9.01448 (\ln \lambda) + 5.55124 (\ln \lambda)^2 - 2.33879 (\ln \lambda)^3 + .514723 (\ln \lambda)^4 - .0447655 (\ln \lambda)^5 \qquad (5)$$

This equation is valid over the 1 to 200 psi region and is represented by the solid line in Figure 10.

Figure 11 is a plot of the scaled positive duration and scaled distance (τ_{1m}' vs λ) data. The scaled positive impulse -- scaled distance data (I_1' vs λ) are plotted in Figure 12. A TNT standard curve from ref. (6) is also plotted in Fig. 12.

3.2 Secondary Shock Measurements

A late secondary shock wave was measured on the 20 psi and below pressure records on all three events. This distinct secondary shock occurred during the negative phase portion of the pressure-time curves (see Appendix C).

Information on the secondary shock is seldom reported, although a review of earlier work reveals its presence on a majority of the data records (e.g., ref. (12)). Because of its hydrodynamic interest and its possible significance for response test applications, secondary shock information is included in this report. The wave shapes can be observed on the records reproduced in Appendix C. The secondary shock amplitudes and times of arrival with respect to the detonation zero pulse are presented in Tables 2, 3, 4, 6, 7 and 8. Figure 13 is a plot of all the

time of arrival data (main shock and secondary shock) as a function of scaled distan
The scaled peak secondary shock pressure is plotted versus scaled distance for all 3 events in Figure 14.

3.3 Temperature Measurements in the AN/FO

The temperature within the AN/FO explosive was monitored with a thermistor. For each event, the thermistor was placed at the center of mass of the hemisphere. It was felt that this location would be warmest if any self heating was to take place in the AN/FO. For the 20 ton charges the thermistor was located 3 feet above the base of the hemisphere. Similarly, for the 100 ton charge the thermistor was located at 5 feet above the base of the hemisphere. In addition, as a second check, another thermistor was placed at the top of the booster on Event III.

The temperature change in the AN/FO mass was of negligible magnitude. The temperature-time data are plotted in Figures 15, 16 and 17 for Events I, II and III respectively. Note the cooling down of the explosive at times. At no time did the recorded temperatures exceed 87°F. The initial temperature of the AN in the hopper car and in the tanker trucks was about 88°F. The ambient air temperature reached a maximum of 105°F during the loading of the 100 ton AN/FO charge for Event III.

4. Discussion and Conclusions

4.1 General

All three charges detonated properly and high order. This is evidenced by the following observations:

a. The pressure-time records show the familiar and classical wave shapes (see Appendix C).

b. The results of the 20 ton shots scale well with the 100 ton data (see Figures 10-12). The extent of data scatter is of the same order as for TNT fired under the same conditions and is attributed to a large extent to the accuracy of the instrumentation and to vagaries of field operation.

c. The results of these large scale trials scale well with the earlier 260 lb to 4000 lb AN/FO results (ref. (2)).

From these observations it can be deduced that:

a. Over the pressure range measured by this project, there is no significant difference between the tagged and bulk-loaded AN/FO charges.

b. The fuel-oil does not settle out of the AN/FO mixture; if this had occurred, it could be expected that the two 20 ton shots would have given different results and would not have scaled to the 100 ton and small size charge results. (Indeed, visual observation during charge preparations and prior to firing time did not show any evidence of oil seepage.)

c. From Figures 10-12, it is evident that there is no significant difference between the pressure-distance characteristics of AN/FO and TNT.

A single frame from one of the Canadian high speed camera films on Event I is shown in Figure 18. This photograph shows the smoothness and symmetry of the shock wave (at 42.9 milliseconds after detonation) produced by the 20 ton bagged AN/FO hemisphere.

Porzel (ref. (15)) and Lehto (ref. (16)) have independently made calculations of the pressure-distance characteristics of the AN/FO system. Both sets of analyses show good agreement with our experimental results in the 1-200 psi region.

The secondary shock (described in Section 3.2) which occurs near the minimum of the negative phase in large explosion trials deserves further attention. For structural elements exposed at low pressures, the secondary shock could be very important. This is because, as the main shock propagates and decays, the ratio of its amplitude to the secondary shock amplitude tends to approach a value of one.

4.2 Equivalent Weight of AN/FO

Long standard NOL procedures for evaluating the peak pressure and impulse TNT equivalent weights (EW_p and EW_I) (ref. (13) and (14)) were used on the present data. A composite of the data presented in Tables 6, 7 and 8 was used in this analysis.

The pressure and impulse versus distance curves for any set of test and standard explosives are seldom parallel. Thus, the single value of average equivalent weight usually given for a test explosive may be misleading because it cannot indicate how it varies as a function of side-on overpressure. To illustrate this functional variation, the EW_p and EW_I for AN/FO are plotted as a function of pressure in Figure 19.

It is interesting to note that although EW_p varies from 0.77 to 1.17, this magnitude of variation in yield is hardly suspected when viewing the pressure-distance curves of Figure 10. Figure 10 shows a scatter of data around either the TNT or AN/FO curves no greater than that usually observed on large scale field trials.

Equivalent weight determinations are an exceedingly sensitive measure of the merits of one explosive compared to another; for some applications it may be too sensitive and hence of little practical significance. And of even lesser practical significance may be the averaged, single-value equivalent weight -- particularly if the average is taken over a large pressure range. The concept of averaged, single-valued equivalent weights is so rooted in the explosives field, however, that although it is with trepidation, we present these values. The user must observe the pressure range over which the averages are taken and be aware of the limitations of these average values.

The average EW_p for AN/FO over the 1 to 200 psi range is 0.94 ± .06[1] relative to TNT using a logarithmic weighting method.[2] Similarly, the average EW_I for AN/FO is 0.71 ± .05. Using logarithmic averaging over the 1-30 psi range (the data range of earlier AN/FO work (ref. (2)), the average EW_p is 0.86 ± .03. In reference (2) we used a linear weighting method when we averaged the equivalent weights and arrived at a figure of 0.82 for the EW_p. The linear weighting gives greater emphasis to the EW_p at the higher pressure levels. Using the present logarithmic method on the Phase I AN/FO Data of reference (2), an average EW_p of 0.87 is obtained over the 1-30 psi range.

4.3 <u>Thermal Stability</u>

The AN/FO temperature data, as presented in Figures 15, 16 and 17, indicate that massive AN/FO has good thermal stability. In the Event I data there is a definite cooling trend. In the case of the Event II and III data there is some evidence of a very slight general warming trend among the cooling and warming cycles. It is on the order of about 1F° per day (the measurements are accurate to within ±1F°). At this point it would appear to be not self heating of the AN/FO but rather external heating from the sun. During the loading of the Event III charge the outside temperature reached about 105°F. AN/FO is a good insulator. The initial temperature of the AN was about 88°F.

It can be concluded that the AN/FO did not exhibit any self heating. No self heating is expected for 500 ton AN/FO charges.

4.4 <u>Concluding Statement.</u>

The results of these AN/FO trials in conjunction with NOL's earlier work on AN/FO have built up a now formidable portfolio of data on the airblast performance

[1] The standard deviation of the mean.

[2] Averaging the values of equivalent weight at logarithmic pressure intervals (i.e., 1, 2, 5, 10, 20, 50, 100 and 200 psi).

of this explosive. AN/FO offers advantages of economy, safety, ease of handling, availability and reproducibility over TNT, slurried explosives, or any other system presently in use for large scale simulation of nuclear air blast.

With these advantages, AN/FO can be seriously considered as a candidate explosive for future large chemical explosive trials.

Acknowledgements

The success of this program could not have been achieved without the excellent cooperation between all the U. S. and Canadian agencies who participated in the AN/FO trials during August 1969. Particular recognition is given to all the DRES personnel who participated unselfishly in the field program. Special thanks are due Fred Davies, Skip Meyers and Ashton Patterson for their superior efforts during the trials.

The authors acknowledge the efforts of Francis B. Porzel and Delbert L. Lehto of NOL on their post-field calculations.

We also take this opportunity to express our appreciation to the personnel from all participating U. S. Agencies and to Ace Explosives Ltd of Calgary, Alberta for their excellent cooperation and performance.

We are grateful to all NOL personnel who contributed to the AN/FO program and to the following individuals who participated in the field program: Maurice Brooks, Roy W. Huff, Christopher Johnson, Richard L. Knodle, Gruver H. Martin, Edwin G. Nacke and Joseph Petes.

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16. Lehto, D. L., NOL Personal Communication, Wundy Method.

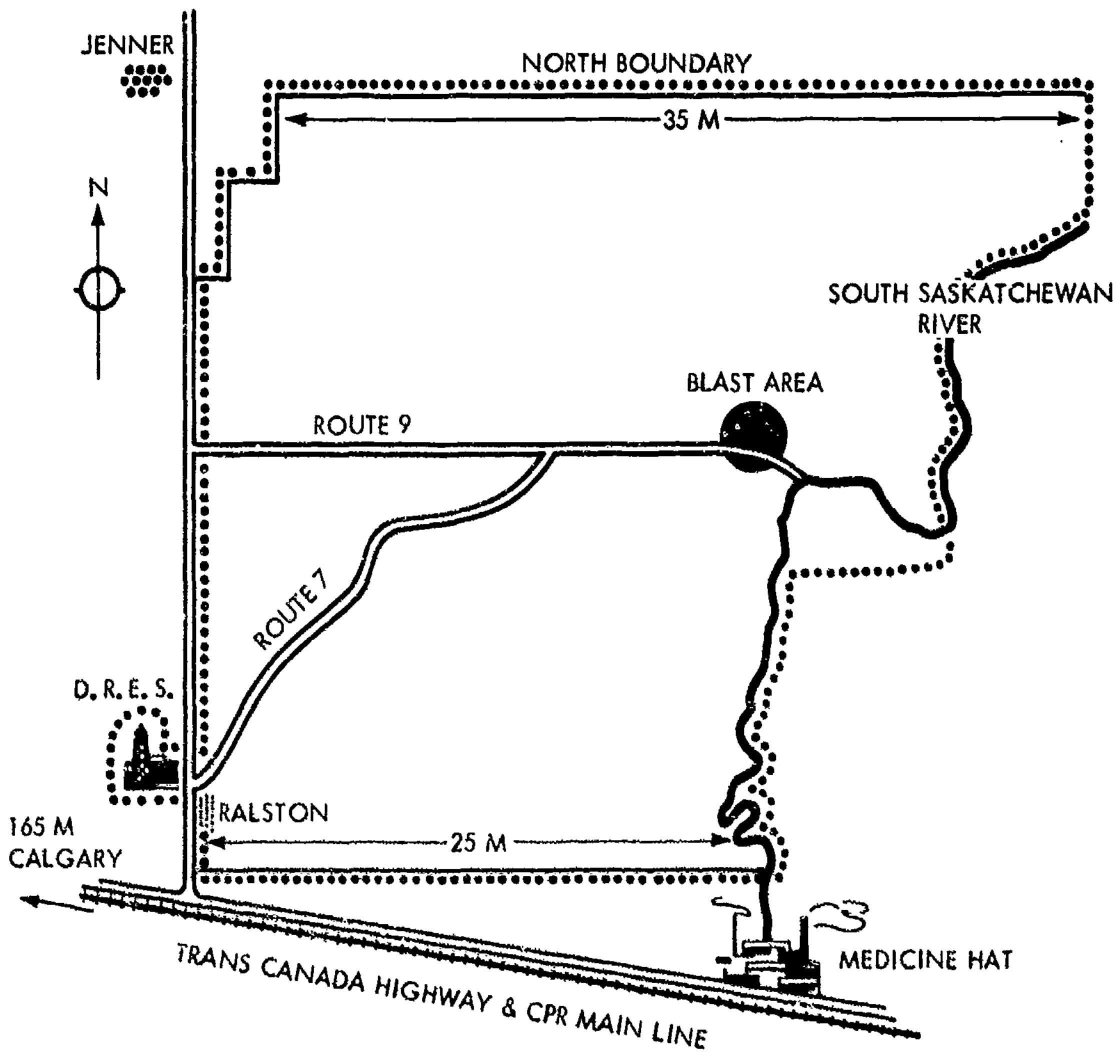


FIG. 1 THE DEFENCE RESEARCH ESTABLISHMENT, SUFFIELD RALSTON, ALBERTA, CANADA

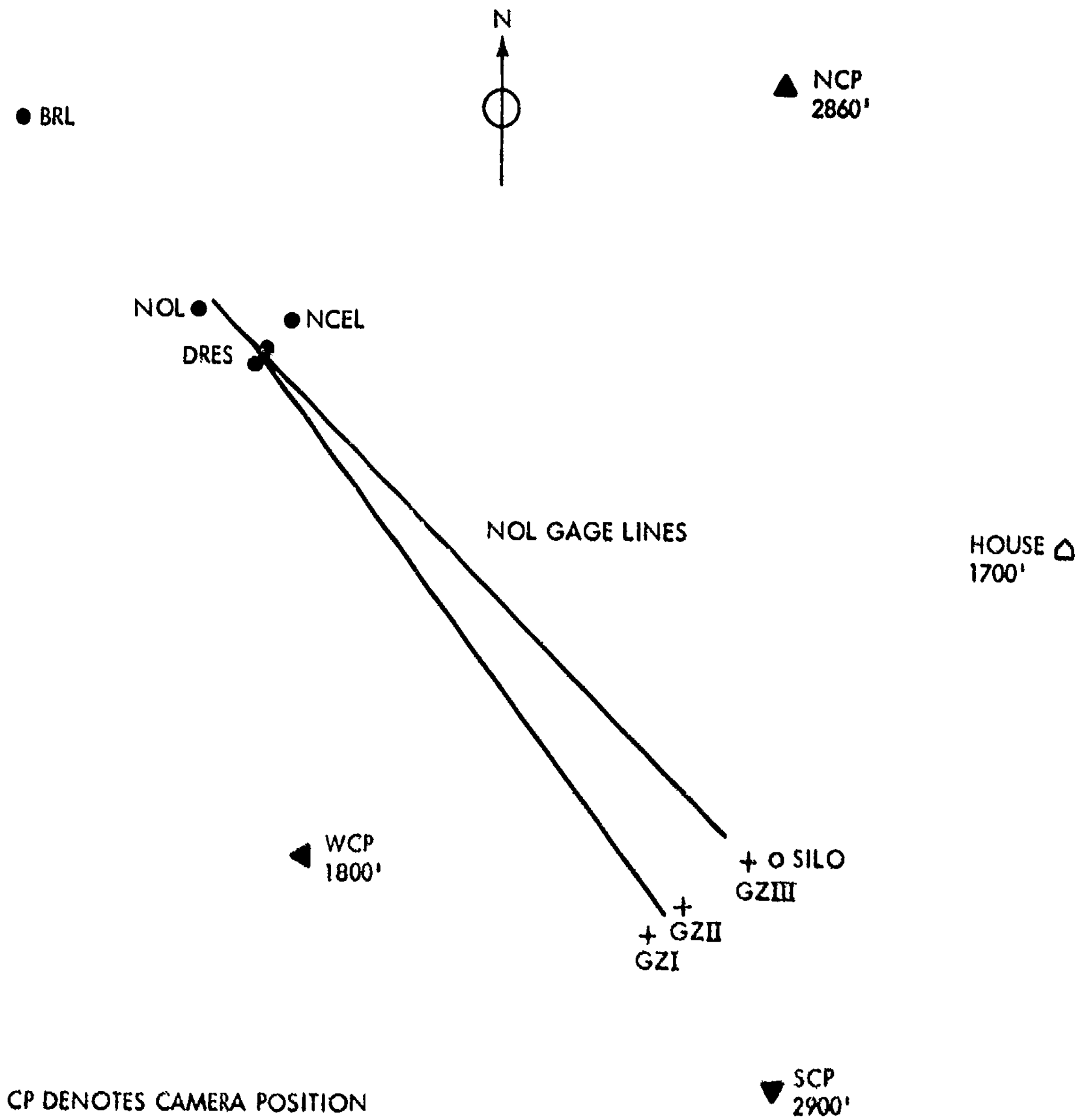
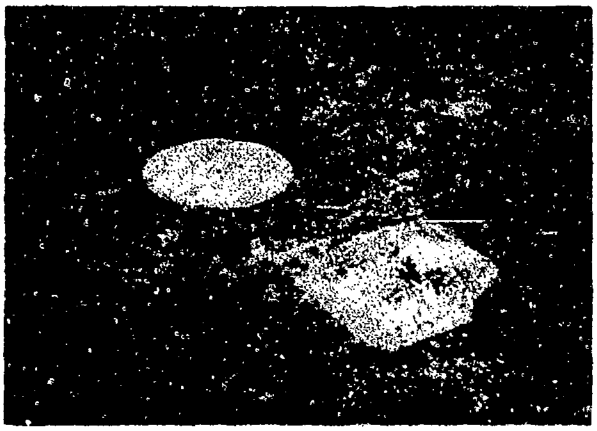
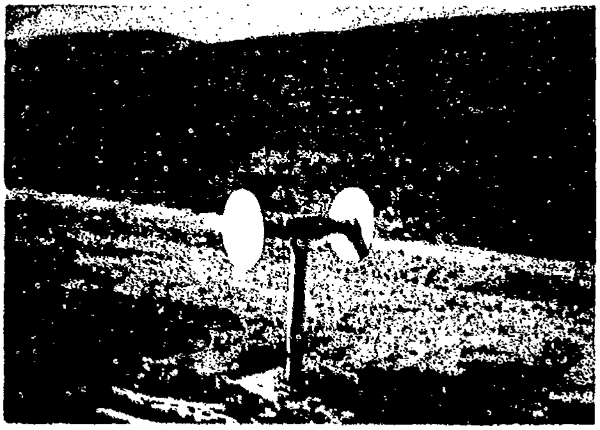


FIG. 2 AN/FO TRIALS LAYOUT



(a) FLUSH BAFFLE. NOL GAGE ON LEFT, BRL GAGE ON RIGHT.



(b) STANDOFF BAFFLE

FIG. 3 AIRBLAST GAGE MOUNTS

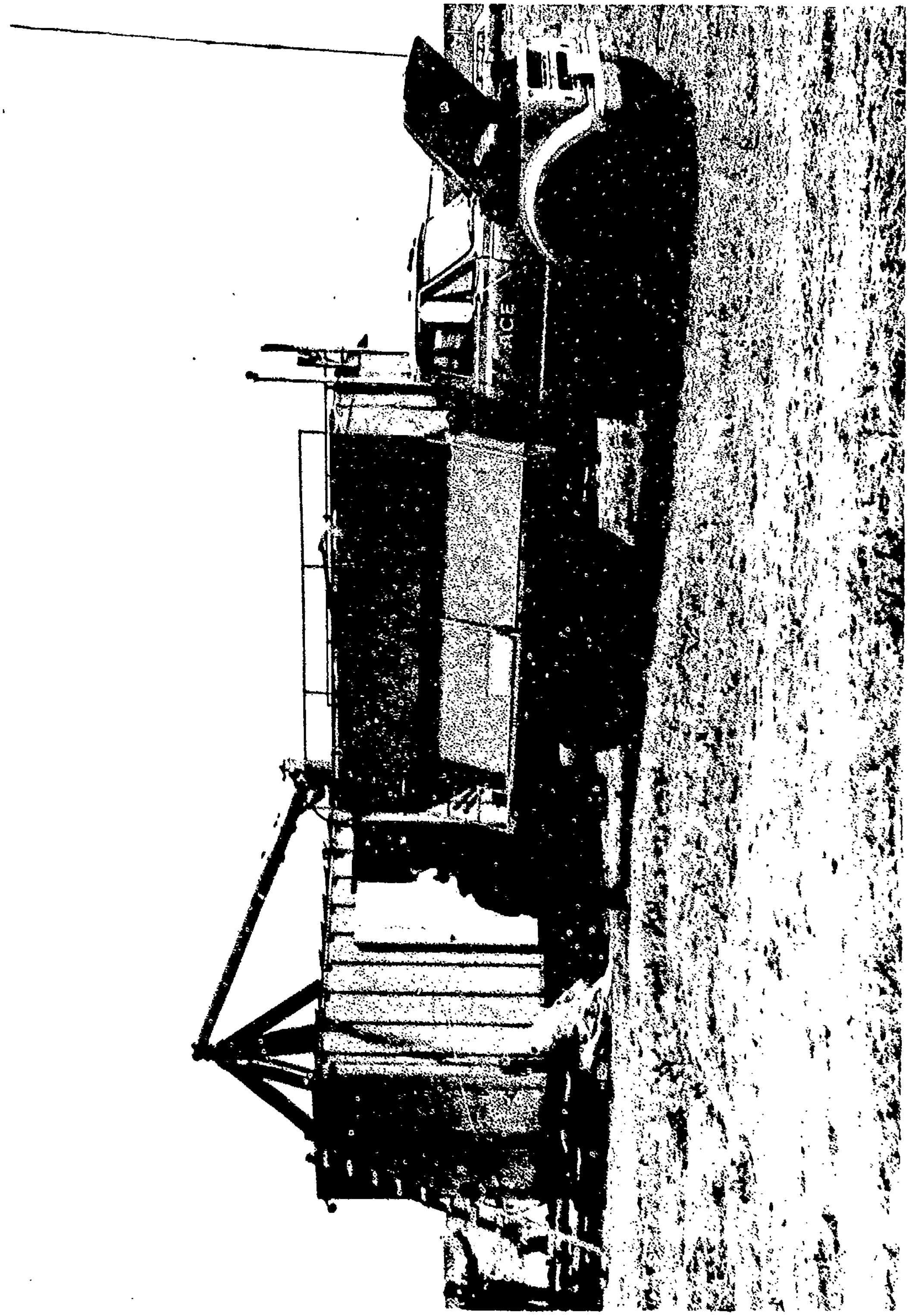


FIG. 4 AN/FO MIXING AND BAGGING OPERATION FOR EVENT I. MIXING TRUCK IS ON RIGHT; BAGGING UNIT IS ON LEFT.

(a) 250 POUND TNT BOOSTER

(b) SECOND LAYER

(c) TENTH LAYER

(d) COMPLETED CHARGE FOR EVENT I

FIG. 6 TANKER TRUCK ON LEFT FEEDING AN INTO AN/FO MIXER TRUCK. AN/FO ENTERING CONTAINER FOR EVENT III.

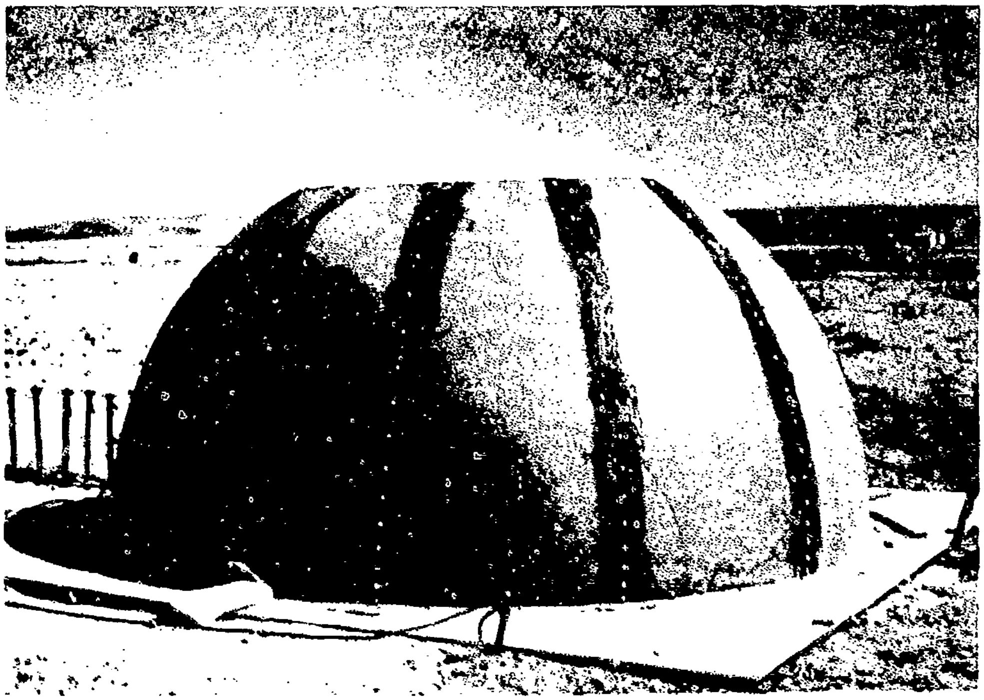


FIG. 7 COMPLETED CHARGE FOR EVENT II. AN/FO WEIGHT: 18.8 TONS

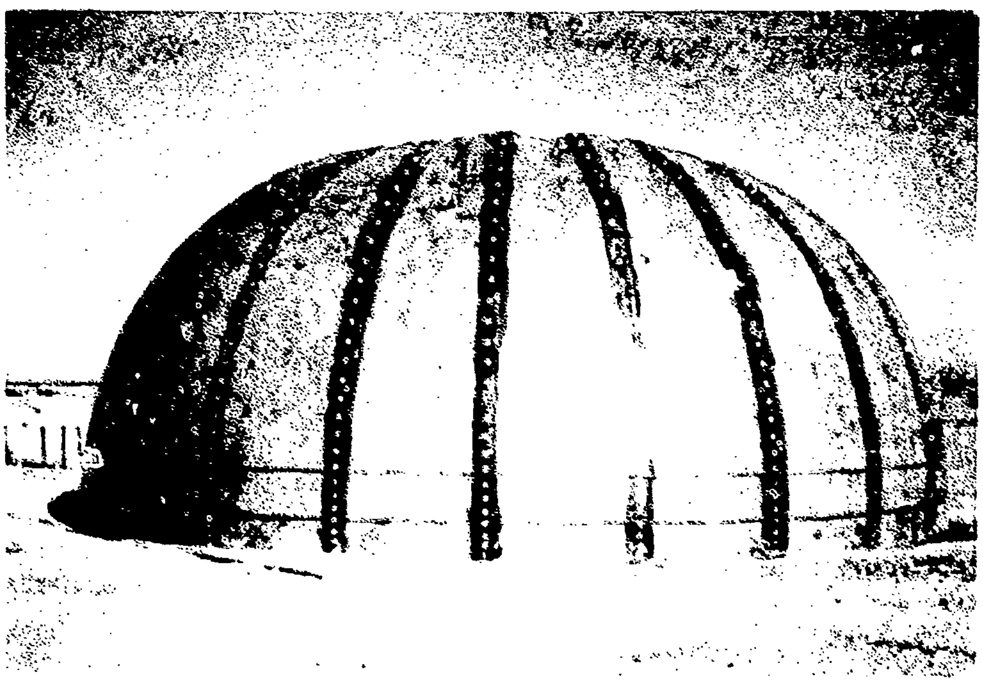


FIG. 8 COMPLETED CHARGE FOR EVENT III. AN/FO WEIGHT: 200 TONS

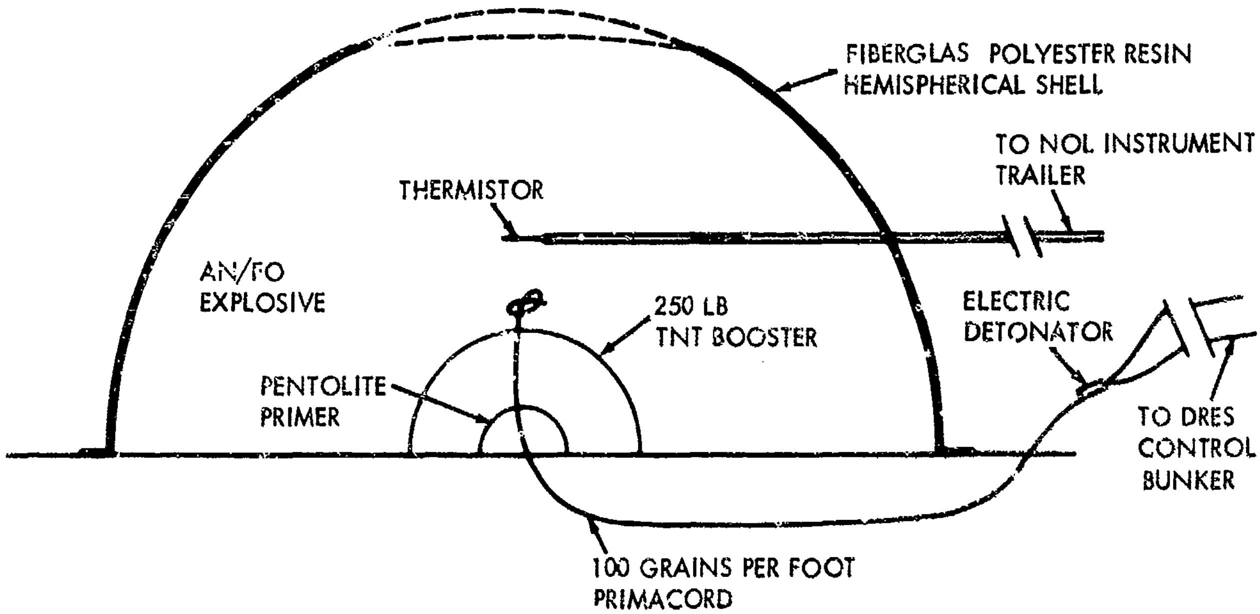


FIG. 9 SCHEMATIC ARRANGEMENT OF THE AN/FO CHARGES OF EVENTS II AND III

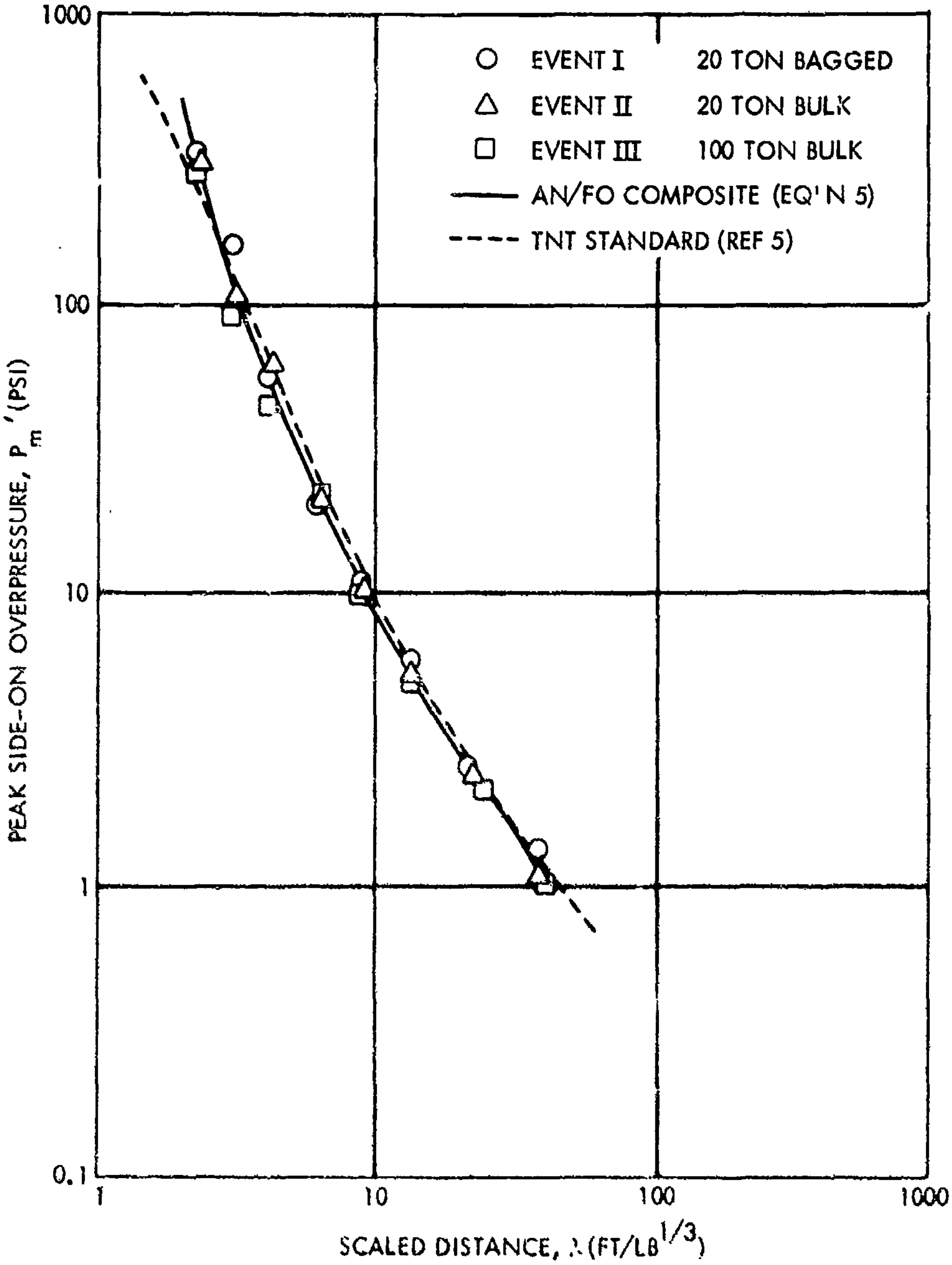


FIG. 10 PEAK PRESSURE VERSUS SCALED DISTANCE FOR AN/FO AT DRES. SCALED TO SEA LEVEL CONDITIONS.

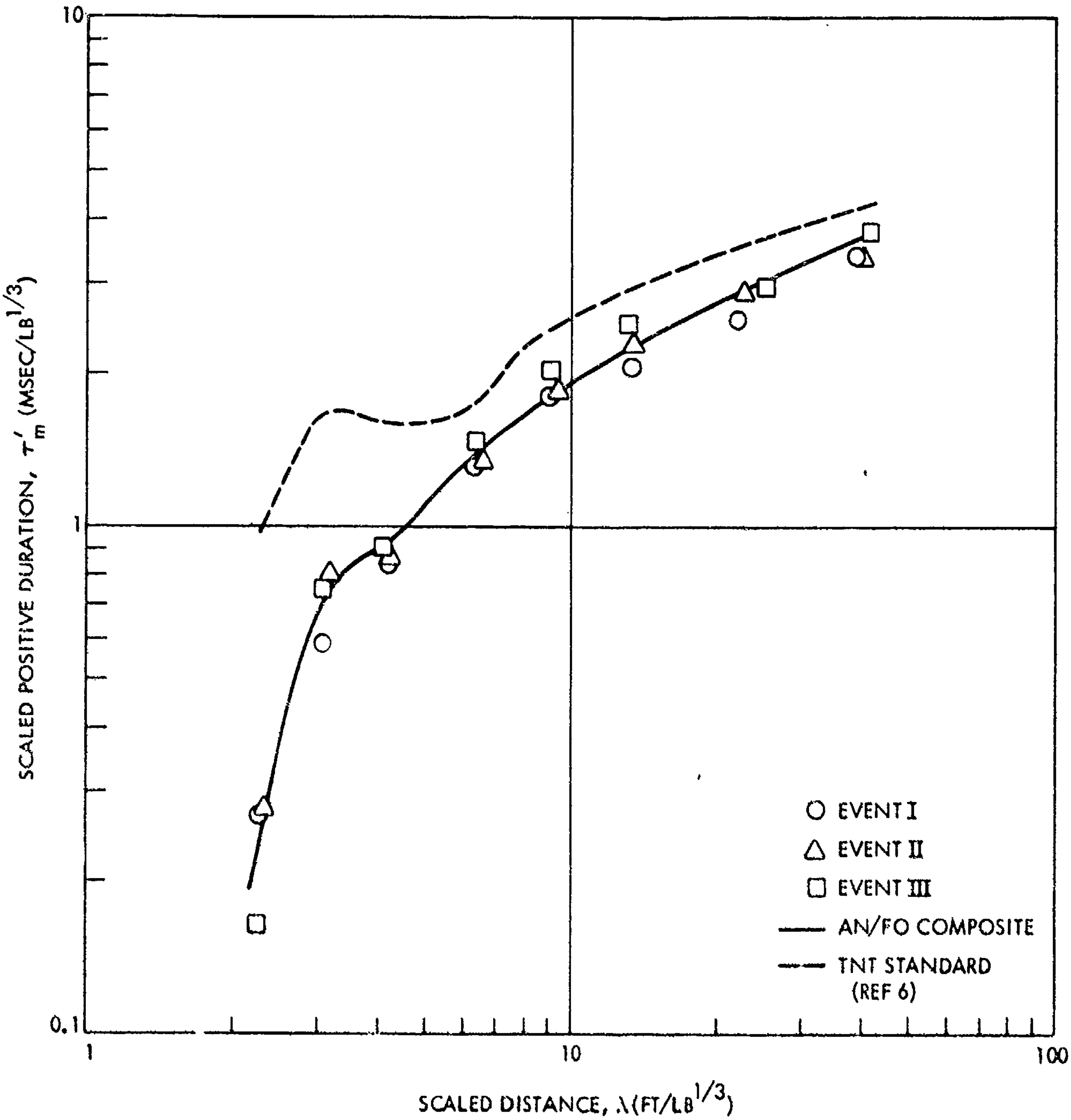


FIG. 11 SCALED POSITIVE DURATION VERSUS SCALED DISTANCE FOR AN/FO AT DRES. SCALED TO SEA LEVEL CONDITIONS.

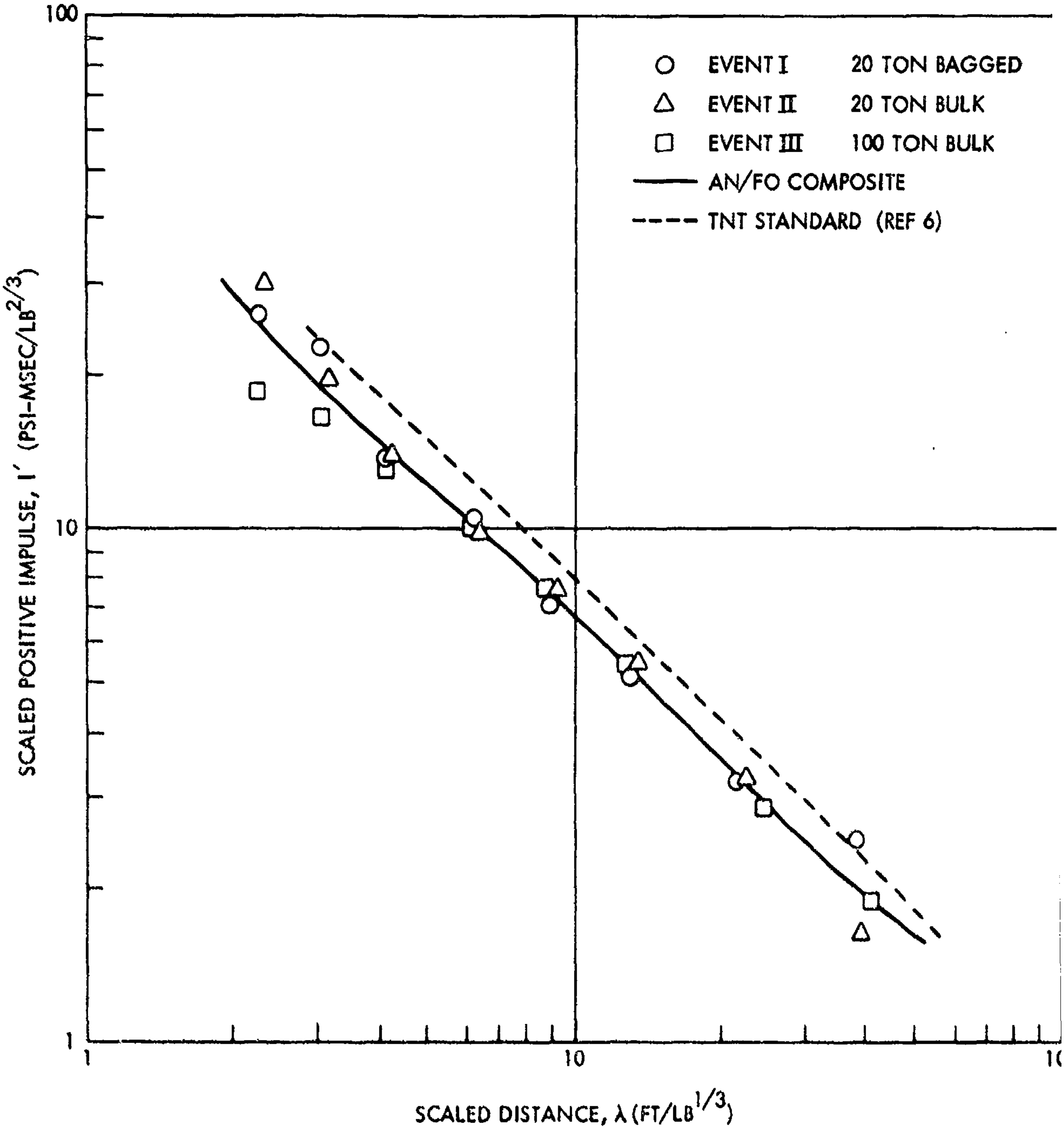


FIG. 12 SCALED IMPULSE VERSUS SCALED DISTANCE FOR AN/FO AT DRES. SCALED TO SEA LEVEL CONDITIONS.

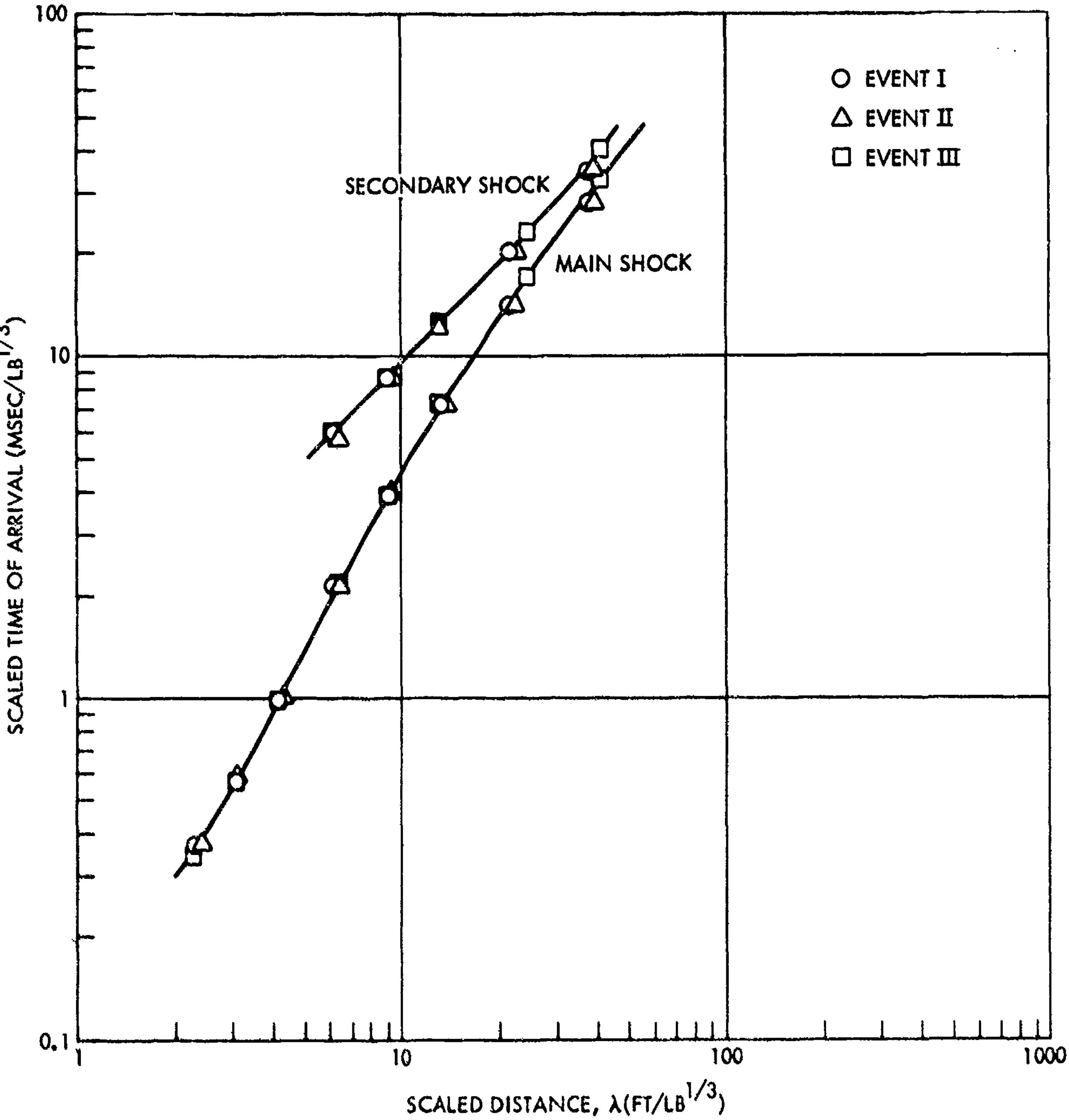


FIG. 13 SCALED TIMES OF ARRIVAL VERSUS SCALED DISTANCE FOR AN/FO AT DRES. SCALED TO SEA LEVEL CONDITIONS.

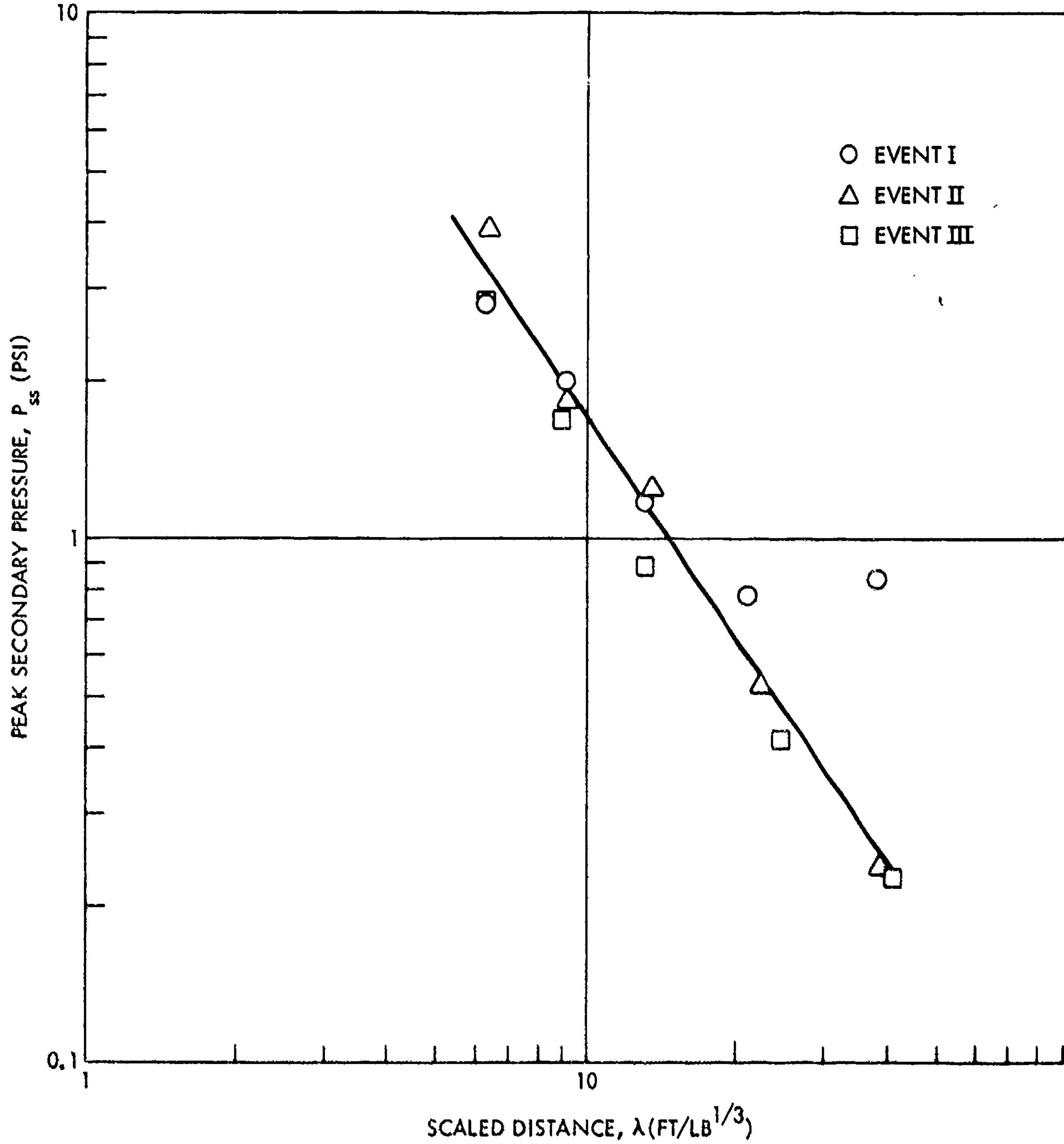


FIG. 14 PEAK SECONDARY SHOCK PRESSURE VERSUS SCALED DISTANCE. AN/FO TRIALS, DRES, AUGUST 1969

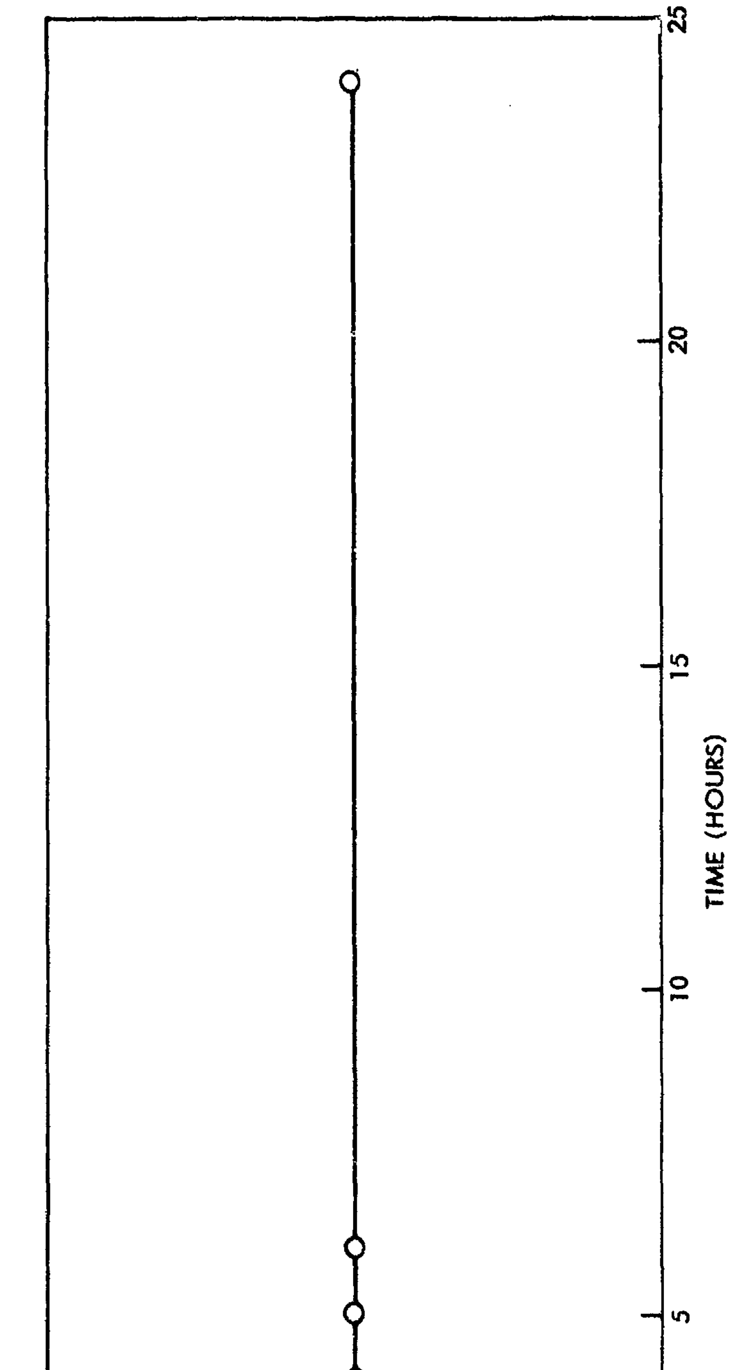


FIG. 15 TEMPERATURE-TIME HISTORY IN AN/FO, EVENT I

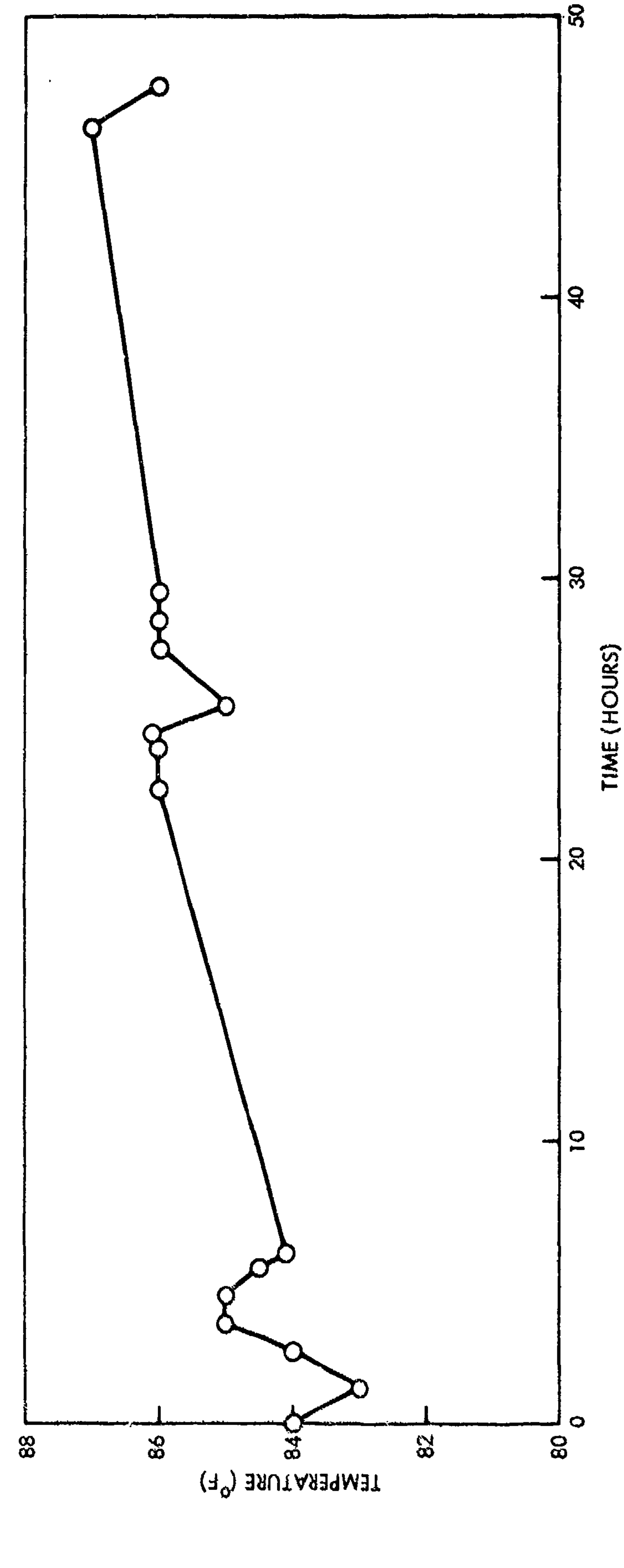


FIG. 16 TEMPERATURE-TIME HISTORY IN AN/FO, EVENT II

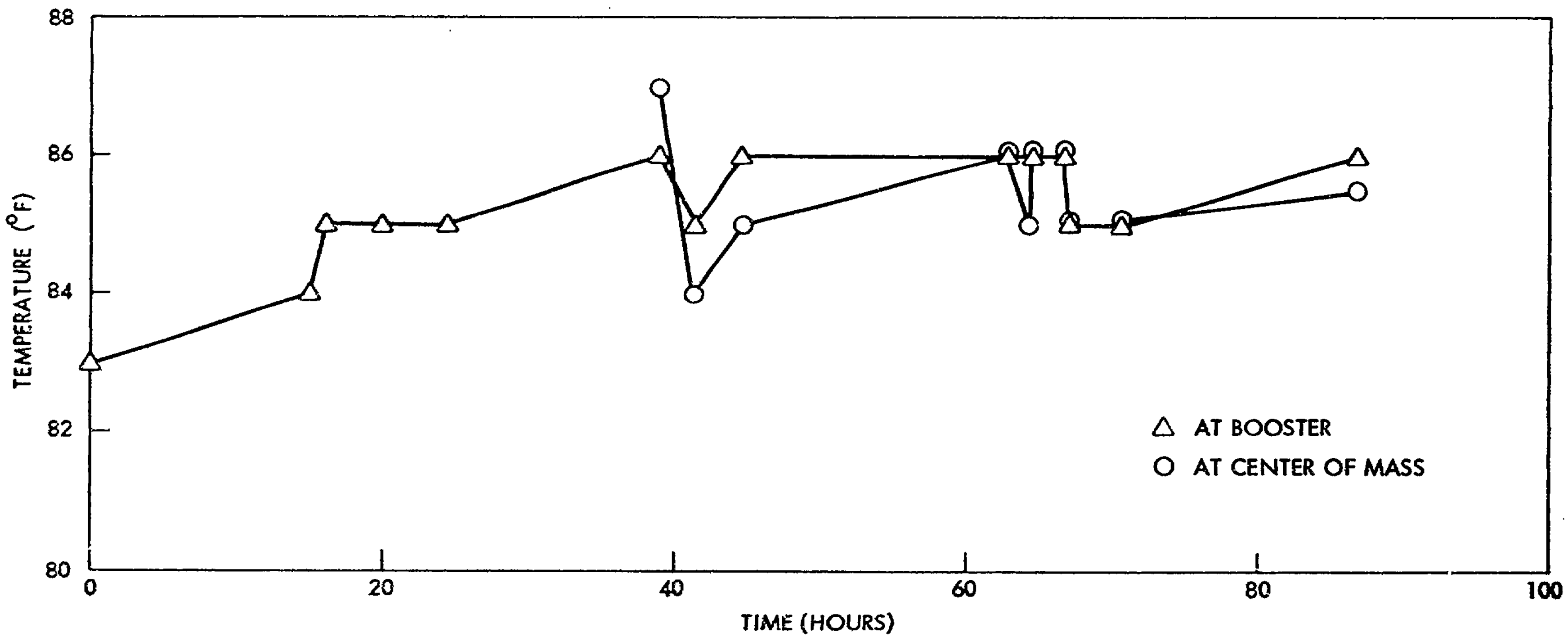


FIG. 17 TEMPERATURE-TIME HISTORY IN AN/FO, EVENT III

FIG. 18 EVENT I, 20 TONS OF BAGGED AN/FO. TIME = 42.9 MILLISECONDS AFTER DETONATION. (DRES PHOTOGRAPH)

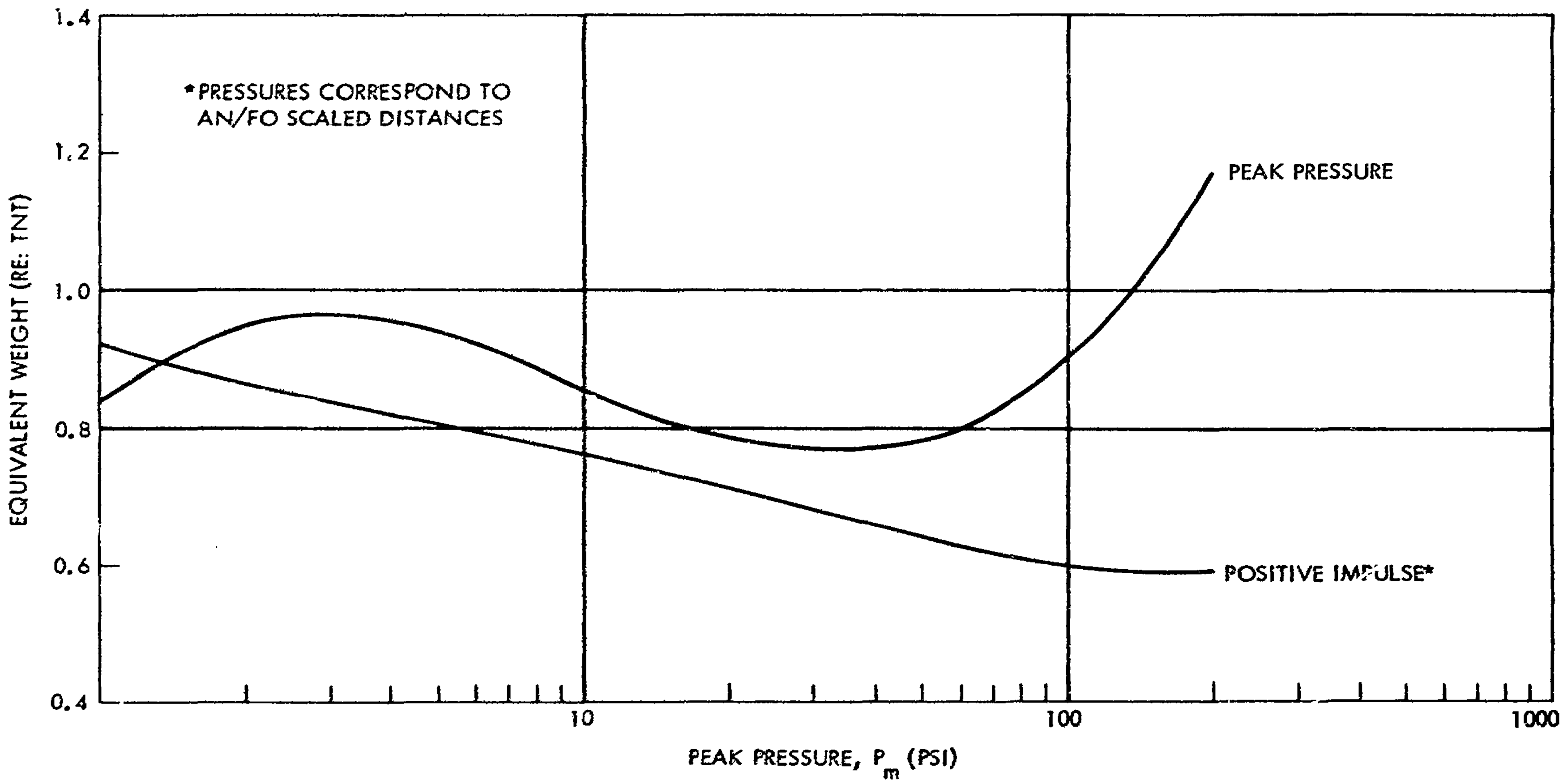


FIG. 19 PEAK PRESSURE AND IMPULSE EQUIVALENT WEIGHT VERSUS PRESSURE.
AN/FO AT DRES, AUGUST 1969

TABLE 1

AN/FO CHARGE CHARACTERISTICS, AN/FO TRIALS, DRES, AUGUST 1969

	EVENT I	EVENT II	EVENT III
BASE DIAMETER-FT	14	14	24.2
WEIGHT OF AN/FO -POUNDS	39,920	37,350	200,650
WEIGHT OF BOOSTER -POUNDS	250	250	250
EFFECTIVE WEIGHT- W-POUNDS	40,170	37,600	200,900
AN/FO DENSITY- GM/CC	0.88[2]	0.839	0.865
FUEL OIL - %[1]	5.85	5.90	5.95

1. METHOD OF REFERENCE 9
2. NOL ESTIMATE, TOTAL VOLUME NOT CONTROLLABLE

TABLE 2

NOL AIRBLAST MEASUREMENTS, EVENT I, UNSCALED DATA
W = 40,170 LBS

R FEET	TOA MSEC	P_m PSI	τ_m MSEC	I PSI-MSEC	TOA'_{ss} MSEC	P_{ss} PSI
80.1	12.5	381	9.22	831		
80.1	12.6	225	17.4	967		
107	19.7	154	20.0	700		
107	19.8	147	20.7	752		
146	33.8	53.2	18.6	334		
146	33.8	51.5	29.8	433		
221	72.2	19.1	45.5	330	205	2.50
221	72.3	20.4	45.8	334	207	2.71
317	135	9.97	63.0	222	289	1.83
317	135	9.14	63.3	229	300	1.88
464	241	5.98	67.7	173	414	1.00
464	241	5.02	74.7	155	415	1.18
772	486	2.34	84.4	106	703	0.69
772	486	2.46	92.7	97.4	690	0.74
1340	959	1.28	117.5	94.2	1210	0.61
1340	960	1.16	117.8	61.7	1210	0.96

TABLE 3

NOL AIRBLAST MEASUREMENTS, EVENT II, UNSCALED DATA
W = 37,600 LBS

R FEET	TOA MSEC	P_m PSI	τ_m MSEC	I PSI-MSEC	TOA_{ss} MSEC	P_{ss} PSI
80.0	12.5	280	9.29	724		
80.0	12.6	290	17.8	1120		
109*	-	-	-	-		
109	20.5	99.9	27.1	603		
145	34.1	57.9	31.9	458		
145	34.1	58.8	27.5	404		
221	71.3	19.9	45.0	278	189	3.66
221	71.4	19.9	48.1	327	195	3.56
317	134	9.40	62.3	235	286	1.83
317	134	9.68	65.2	235	288	1.55
464	241	4.78	79.2	174	404	1.12
464	241	5.14	77.0	164	413	1.19
772	485	2.27	98.2	101	693	0.49
772*	-	-	-	-	-	-
1340	956	1.00	116	49.9	1190	0.22
1340*	-	-	-	-	-	-

* NO SIGNALS RECORDED

TABLE 4

NOL AIRBLAST MEASUREMENTS, EVENT III, UNSCALED DATA
W = 200,900 LBS

R FEET	TOA MSEC	P_m PSI	τ_m MSEC	I PSI-MSEC	TOA_{ss} MSEC	P_{ss} PSI
136	20.4	326	9.86	842		
136	20.4	197	-Δ	1190Δ		
184	33.6	83.8	44.9	914		
184*	33.8	-	-	-		
249	58.7	42.8	55.0	763		
249	58.8	39.2	55.6	702		
378	128	19.5	90.7	547	362	2.20
378	128	20.4	87.4	585	365	3.06
542	238	9.16	124	410	514	1.54
542	239	9.34	122	428	509	1.58
794	432	4.85	152	294	749	0.80
794	432	4.70	149	301	763	0.84
1490	1020	1.86	205	174	1420	0.36
1490	1020	2.02	152	139	1420	0.41
2460	1870	0.96	219	98.7	2300	0.22
2460	1870	0.96	225	110.0	2350	0.20

* NO SIGNALS RECORDED AFTER SHOCK ARRIVAL
Δ SIGNAL DID NOT CROSS BASELINE; IMPULSE WAS ESTIMATED

TABLE 5

AMBIENT CONDITIONS AND SCALING FACTORS[1] FOR AN/FO TRIALS AT DRES, AUGUST 1969

EVENT	W	P_{o_2}	T_{o_2}	SCALING FACTORS			
	LBS	PSI	°R	PRESSURE	DISTANCE	TIME	IMPULSE
I	40,170	13.58	544.5	1.0825	35.165	34.322	31.713
II	37,600	13.565	552.5	1.0837	34.411	33.342	30.768
III	200,900	13.533	525.2	1.0862	60.205	59.832	55.081

[1] TO SEA LEVEL CONDITIONS: $P_{o_1} = 14.7$ PSI AND $T_{o_1} = 519$°R

TABLE 6

NOL SCALED AIRBLAST MEASUREMENTS, AN/FO EVENT I, W = 40,170 LBS

λ FT/LB$^{1/3}$	TOA' MSEC/LB$^{1/3}$	P'_m PSI	τ'_m MSEC/LB$^{1/3}$	I' PSI-MSEC/LB$^{2/3}$	TOA'$_{ss}$ MSEC/LB$^{1/3}$	P'_{ss} PSI
2.28	0.366	328	0.269	26.2		
3.05	0.573	163	0.593	22.9		
4.16	0.96	56.7	0.869	13.6		
6.29	2.11	21.4	1.33	10.5	6.00	2.81
9.02	3.92	10.4	1.84	7.11	8.58	2.00
13.2	7.03	5.95	2.07	5.17	12.1	1.18
21.9	14.1	2.60	2.58	3.21	20.3	0.78
38.2	28.0	1.32	3.43	2.46	35.3	0.84

TABLE 7

NOL SCALED AIRBLAST MEASUREMENTS, AN/FO EVENT II, W = 37,600 LBS

λ FT/LB$^{1/3}$	TOA' MSEC/LB$^{1/3}$	P'_m PSI	τ'_m MSEC/LB$^{1/3}$	I' PSI-MSEC/LB$^{2/3}$	TOA'$_{ss}$ MSEC/LB$^{1/3}$	P'_{ss} PSI
2.32	0.376	309	0.279	30.0		
3.16	0.615	108	0.813	19.6		
4.22	1.02	63.2	0.890	14.0		
6.42	2.14	21.6	1.39	9.83	5.76	3.91
9.22	4.03	10.3	1.91	7.64	8.61	1.83
13.5	7.24	5.38	2.34	5.50	12.1	1.25
22.4	14.5	2.46	2.94	3.28	20.8	0.53
39.0	28.7	1.08	3.48	1.62	35.7	0.24

TABLE 8

NOL SCALED AIRBLAST MEASUREMENTS, AN/FO EVENT III, W = 200,900 LBS

λ FT/LB$^{1/3}$	TOA' MSEC/LB$^{1/3}$	P'_m PSI	τ'_m MSEC/LB$^{1/3}$	I' PSI-MSEC/LB$^{2/3}$	TOA'$_{ss}$ MSEC/LB$^{1/3}$	P'_{ss} PSI
2.26	0.341	284	0.165	18.4		
3.05	0.563	91.0	0.750	16.6		
4.14	0.982	44.5	0.925	13.3		
6.28	2.14	21.7	1.49	10.2	6.08	2.86
9.00	3.99	10.1	2.05	7.61	8.55	1.69
13.2	7.22	5.19	2.52	5.41	12.6	0.89
24.7	17.0	2.11	2.98	2.85	23.7	0.42
40.9	31.2	1.04	3.71	1.89	38.9	0.23

APPENDIX A

NOL INSTRUMENTATION

The pressure gages used in these tests were variable reluctance transducers manufactured by Consolidated Controls Corporation. These are frequency modulated (FM) gages which operate in the standard IRIG 13 and IRIG 14 frequency bands, 14.5 kHz and 22.0 kHz respectively.

The gage signals were transmitted to the instrumentation trailer, some 3000 fee from the G. Z.'s, over WD1/TT field telephone wire. The signal cables were terminated by United Transformer company model UTC A-12 transformers and the signals then recorded on magnetic tape recorders. Three 14-track recorders were used: 1) Ampex FR 1800L, 2) Consolidated Electrodynamics Corporation VR 3300, and 3) Sangamo 4700. The FM signals were all recorded in the direct record (amplitude modulated) mode.

Pressures were measured at eight distances on each event, with two pressure transducers at each distance. A time zero pulse, provided by the DRES control bunker, was also recorded on each shot. Thus, 17 channels of information were recorded on each event. The incoming signals were divided in such a way that any two of the three recorders contained a complete set of records

On playback, the signals were played through a tunable discriminator manufactur by Electro-Mechanical Research Corporation and recorded on a Midwestern oscillograp The oscillograph records of pressure versus time were digitized using the NOL Telereader system.

The system frequency response was flat from D.C. to 1 kHz, the gages being the response-limiting element. This relatively low upper frequency response was sufficient for the long duration signals expected and observed on these trials. This low upper frequency response manifests itself as a finite rise-time and a reduction in the apparent peak amplitude of the observed gage signals. Using the extrapolation techniques described in Appendix B, the observed signals are extrapolated back to zero time (shock arrival). This procedure corrects for the upper frequency limitations of the system.

The temperature of the explosive in each charge was monitored by thermistors. A General Radio Type 1650-A Impedance Bridge was used to read the thermistor resistance. The accuracy of this measuring system was $\pm 1F^{o}$.

APPENDIX B

DATA ANALYSIS PROCEDURES

A least squares fit of the form

$$P = A(\Delta f) + B(\Delta f)^2 + C(\Delta f)^3 + D(\Delta f)^4 + E(\Delta f)^5 , \qquad \text{(B-1)}$$

was made to the calibration data for each gage for each event. A 3rd, 4th or 5th degree polynomial was chosen for each set of calibration data. The smallest degree of fit for optimum accuracy was selected for each set of calibration data.

The digitized data for each P-t record, along with the coefficients of the gage calibration data (Equation (B-1)) was analyzed using the IBM 7090/7094 computer. The calculational methods used and a listing of the computer program are presented herewith on pages B-3 to B-6.

Extrapolated positive duration was determined by fitting an equation of the form:

$$t = \tau_{2m} e^{\beta p} , \qquad \text{(B-2)}$$

to the pressure-time data in the last quarter of the apparent positive phase. The value of τ_{2m} is the extrapolated positive duration.

Extrapolated peak pressure was determined by fitting an equation of the form:

$$p = P_{2m} e^{\alpha t} \quad (\alpha < 0), \qquad \text{(B-3)}$$

to the pressure-time data in the first half of the apparent positive phase. The value of P_{2m} is the extrapolated peak pressure.

Positive Impulse is defined by the equation:

$$I_2 = \int_0^{\tau_2} p(t)\, dt. \qquad \text{(B-4A)}$$

In these calculations, the impulse was determined in two parts. Over most of the positive phase, after some initial time interval Δt, the impulse was determined by the equation,

$$I = \int_{\Delta t}^{\tau_2} p(t)\, dt, \qquad \text{(B-4B)}$$

where Δt is a small value of time, which accounts for both the rise-time of the observed signal and any observed early-time gage malfunctions. Over this range (Δt to τ_2), the impulse was determined by the use of the trapezoid rule -- that is, a numerical integration of the pressure-time data.

The impulse in the time increment (Δt) between shock arrival and the first pressure point was determined in the following way.

$$p = P_{2m} e^{\alpha t} , \tag{B-3}$$

$$\Delta I = \int_0^{\Delta t} p(t)\, dt , \tag{B-4C}$$

$$\Delta I = P_{2m} \int_0^{\Delta t} e^{\alpha t}\, dt , \tag{B-4D}$$

$$\Delta I = \frac{P_{2m}}{\alpha} \left(e^{\alpha \Delta t} - 1 \right) . \tag{B-4E}$$

This impulse increment (Equation (B-4E)) was then added to the impulse determined for the remainder of the positive phase to arrive at the total positive impulse (that is $I_2 = I + \Delta I$).

```
      COMMON    X(4,500),A(10),P(500),LL(50),TL(500),PT(500),TPLOT(500)
     1PL(500),DUMMY(50),IX(2,500),T(500),U(500),TITLE(24),D1,G(500)
C
C     JCASE IS THE NUMBER OF RECORDS BEING PROCESSED
      READ(5,5000)JCASE
      DO 999 KIK=1,JCASE
      READ(5,5100)(TITLE(I),I=1,4)
      WRITE(6,5110)(TITLE(I),I=1,4)
C     IDEG IS THE DEGREE OF THE POLYNOMIAL USED TO FIT THE CALIBRATION
C     DATA FOR THAT GAGE AND SHOT
      READ(5,5000)IDEG
C     XCAL AND YCAL AR5 THE SIZE OF THE X AND Y CALIBRATION STEPS.
      READ(5,5140)XCAL,YCAL
C     XCAL IS IN MILLISECS AND YCAL IS IN HERTZ.
C     IXSCA AND IYSCA ARE TELEREADEX CALIBRATIONS
      READ(5,5130)IXSCA,IYSCA
      XSCA=IXSCA
      YSCA=IYSCA
C     ITOA IS THE SHOCK TIME OF ARRIVAL OBTAINED FROM THE RECORD
C     IDUM IS A DUMMY VARIABLE
      READ(5,5130)ITOA,IDUM
      TOA=ITOA
      DUMMY=IDUM
C     THE A(J) ARE THE COEFFICIENTS OF THE CALIBRATION CURVE FIT
      DO 10 J=1,IDEG
   10 READ(5,5150)A(J)
      M=0
C     IX(1,L) AND IX(2,L) ARE THE POINTS PUNCHED BY THE TELEREADER
C     SYSTEM
      DO 20 L=1,500
      READ(5,5130)IX(1,L),IX(2,L)
      X(1,L)=IX(1,L)
      X(2,L)=IX(2,L)
      IF(X(1,L).EQ.999999.)GO TO 25
      M=M+1
   20 CONTINUE
   25 MM=M
C
      WRITE(6,5200)MM
      XS1=ABS(XSCA)
      XS2=ABS(XCAL)
      YS1=ABS(YSCA)
      YS2=ABS(YCAL)
C
      DO 40 JJ=1,MM
C     X(3,JJ) IS THE TIME  CALCULATED FOR EACH POINT
      X(3,JJ)=(X(1,JJ)/XS1)*XS2
C     X(4,JJ) IS THE FREQUENCY DEVIATION CALCULATED FOR EACH POINT
      X(4,JJ)=(X(2,JJ)/YS1)*YS2
      T(JJ)=X(3,JJ)
      U(JJ)=X(4,JJ)
   40 CONTINUE
C
      WRITE(6,5210)
      DO 90 K=1,MM
C     P(K) IS THE OVERPRESSURE CALCULATED FROM EACH FREQUENCY DEVIATION
      P(K)=0.
      DO 80 KK=1,IDEG
      P(K)=P(K)+A(KK)*X(4,K)**KK
   80 CONTINUE
```

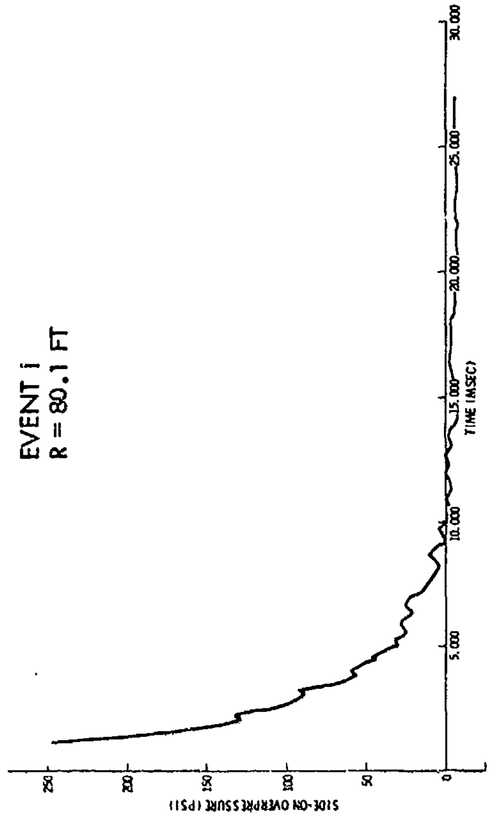
```
   90 CONTINUE
C
      G(1)=0.
      NNN=MM-1
C     THIS SECTION CALCULATES IMPULSE BY THE TRAPEZOID RULE
      DO 200 LK=1,MM
      IN=LK-1
      DELT=ABS(T(LK+1)-T(LK))
      IF(P(LK).EQ.0.)GO TO 150
      GO TO 155
  150 G(LK)=0.
      GO TO 160
  155 G(LK)=G(IN)+.5*(P(LK)+P(LK+1))*DELT
  160 WRITE(6,5220)T(LK),P(LK),G(LK)
  200 CONTINUE
C
      CALL DURAT(T,U,P,MM)
C     DURAT DETERMINES BOTH THE ACTUAL CROSSING TIME OF THE SIGNAL AND
C     ALSO THE EXTRAPOLATED DURATION
C
      CALL PRES1(D1,T,P,MM)
C     PRES1 CALCULATES  THE EXTRAPOLATED PEAK PRESSURE
C
  999 CONTINUE
 5000 FORMAT(1I5)
 5100 FORMAT(4A6)
 5110 FORMAT(1H1,4A6)
 5130 FORMAT(1I7,1I10)
 5140 FORMAT(2E10.4)
 5150 FORMAT(E14.5)
 5200 FORMAT(1H0,2HM=,1I5)
 5210 FORMAT(1H0,44HTIME(MSEC)  PRESSURE(PSI)  IMPULSE(PSI-MSEC),//)
 5220 FORMAT(3F10.4)
      STOP
      END
$IBFTC SDURA
      SUBROUTINE DURAT(T,U,P,MM)
      COMMON    X(4,500),A(10),P(500),LL(50),TL(500),PT(500),TPLOT(500),
     1PL(500),DUMMY(50),IX(2,500),T(500),U(500),TITLE(24),D1,G(500)
      DO 30 NN=1,50
      LL(NN)=0
   30 CONTINUE
      K=1
      KI=0
      DO 430 I=1,MM
      IF(U(I))430,420,430
  420 LL(K)=I
      K=K+1
      KI=KI+1
  430 CONTINUE
      IF(LL(2)-KI)500,440,440
  440 LZ2=LL(2)
      T2=T(LZ2)
  445 IF(LL(3)-KI)510,450,450
  450 LZ3=LL(3)
      T3=T(LZ3)
  455 IF(LL(4)-KI)520,460,460
  460 LZ4=LL(4)
      T4=T(LZ4)
  465 IF(LL(5)-KI)530,470,470
```

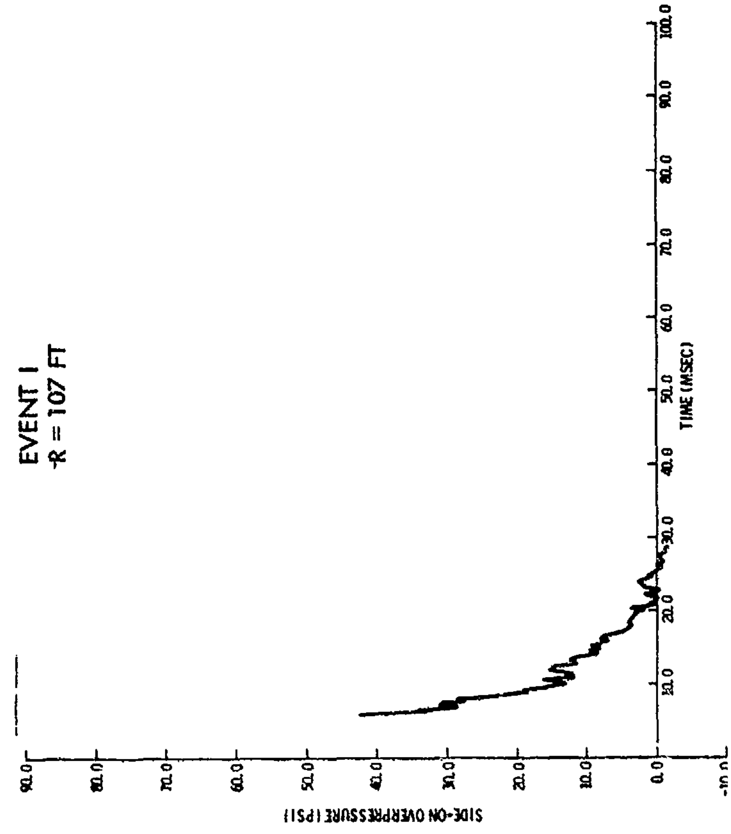
```
  470 LZ5=LL(5)
      T5=T(LZ5)
  475 IF(LL(6)-KI)540,480,480
  480 LZ6=LL(6)
      T6=T(LZ6)
      GO TO 600
  500 T2=1.E4
      GO TO 445
  510 T3=1.E4
      GO TO 455
  520 T4=1.E4
      GO TO 465
  530 T5=1.E4
       GO TO 475
  540 T6=1.E4
  600 D1=AMIN1(T2,T3,T4,T5,T6)
      D2=.75*D1
      KK=0
      TX=0.
      PT=0.
      TX2=0.
      TXPT=0.
      P2=0.
      DO 700 N=1,500
      IF(D2-T(N))620,620,700
  620 IF(D1-T(N))700,630,630
  630 TL(N)=ALOG(T(N))
      TX=TX+TL(N)
      PT=PT+P(N)
      P2=P2+P(N)**2
      TXPT=TXPT+TL(N)*P(N)
      KK=KK+1
  700 CONTINUE
      XKK=KK
      BD=(XKK*TXPT-TX*PT)/(XKK*P2-PT**2)
      AD=(TX-BD*PT)/XKK
  710 D3=EXP(AD)
      D6=6.*D1
      WRITE(6,2220) D1
      WRITE(6,2230) D3
 2220 FORMAT(1H0,10X,33HAPPARENT POSITIVE DURATION(MSEC)=,1F10.4//)
 2230 FORMAT(10X,37HEXTRAPOLATED POSITIVE DURATION(MSEC)=,1F10.4)
      RETURN
      END
$IBFTC SPRES
      SUBROUTINE PRES1(D1,T,P,MM)
      COMMON    X(4,500),A(10),P(500),LL(50),TL(500),PT(500),TPLOT(500)
     1PL(500),DUMMY(50),IX(2,500),T(500),U(500),TITLE(24),D1,G(500)
      DP=.5*D1
      MI=0
      XT=0.
      YP=0.
      XT2=0.
      CROS=0.
      DO 700 NN=2,MM
      IF(T(NN).GT.DP)GO TO 700
      PL(NN)=ALOG(P(NN))
      XT=XT+T(NN)
      YP=YP+PL(NN)
      XT2=XT2+T(NN)**2
```

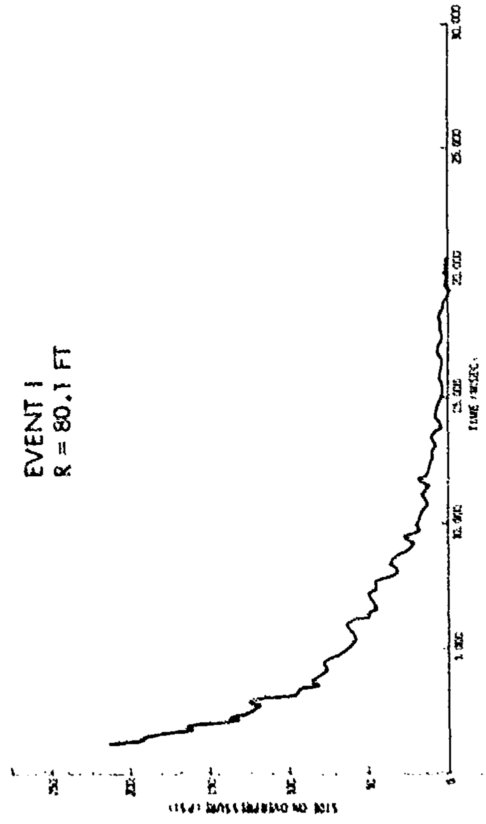
```
      CROS=CROS+T(NN)*PL(NN)
      MI=MI+1
  700 CONTINUE
      XMI=MI
      BP=(XMI*CROS-XT*YP)/(XMI*XT2-XT**2)
      AP=(YP-BP*XT)/XMI
      WRITE(6,2980)XMI,BP,AP
      PME=EXP(AP)
      WRITE(6,3000)PME
 2980 FORMAT(1H0,10HXMI,BP,AP=,3F10.4)
 3000 FORMAT(1H0,10X,32HEXTRAPOLATED PEAK PRESSURE(PSI)=,1F10.4)
      RETURN
      END
$DATA
```

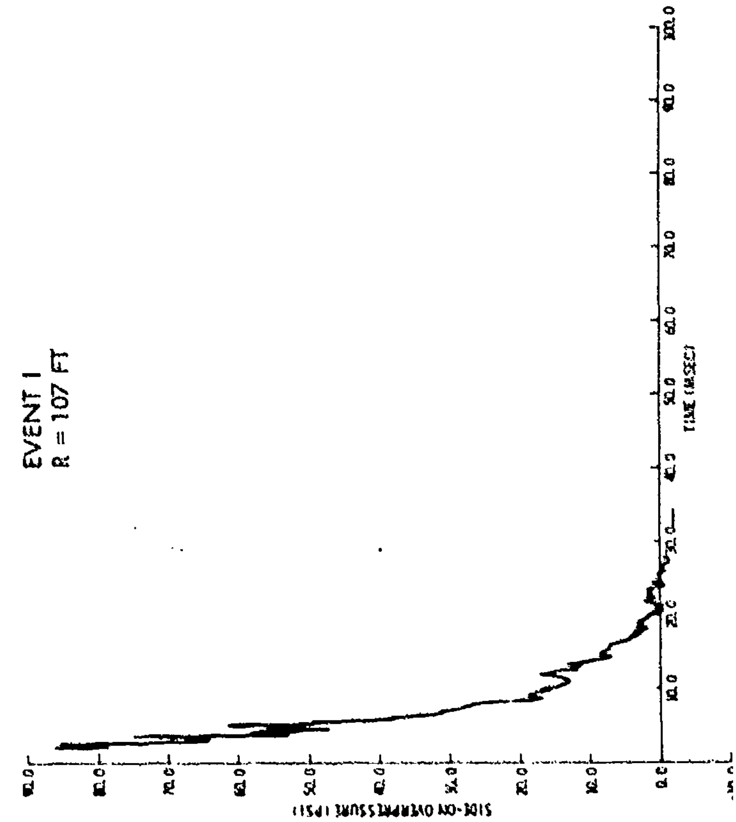
APPENDIX C

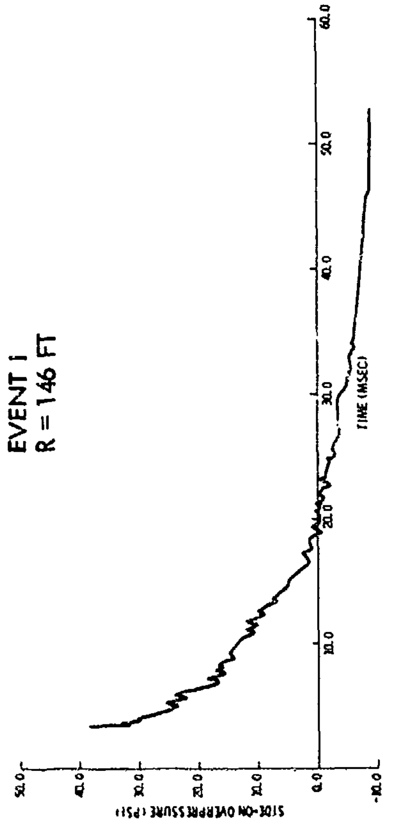
The Pressure-Time Curves

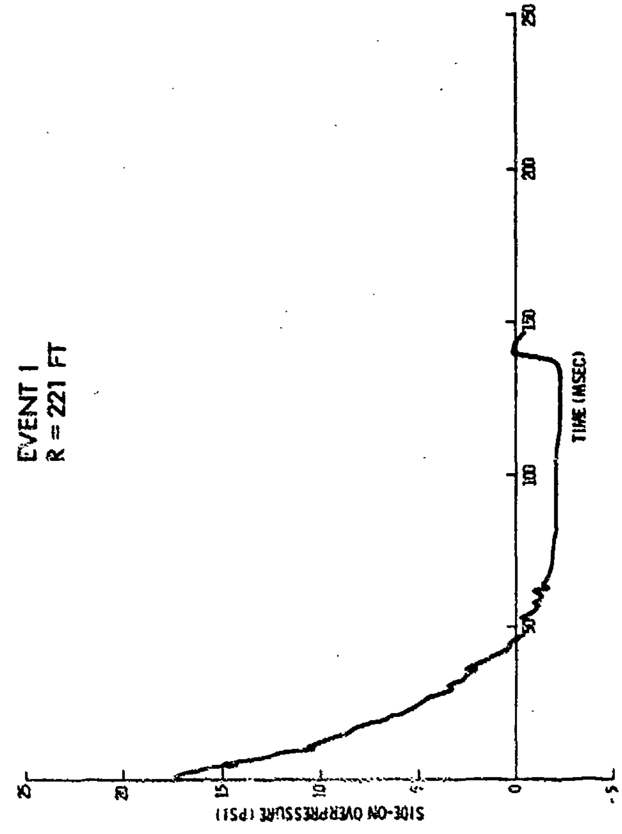

EVENT I
R = 80.1 FT
TIME (MSEC)
SIDE-ON OVERPRESSURE (PSI)

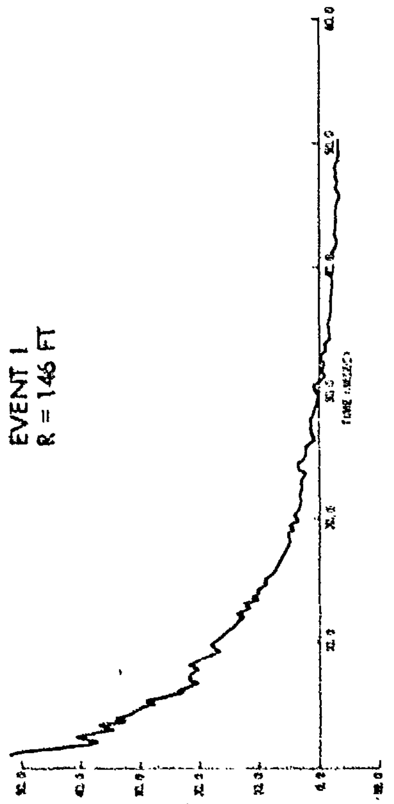

EVENT I
R = 107 FT
TIME (MSEC)
SIDE-ON OVERPRESSURE (PSI)

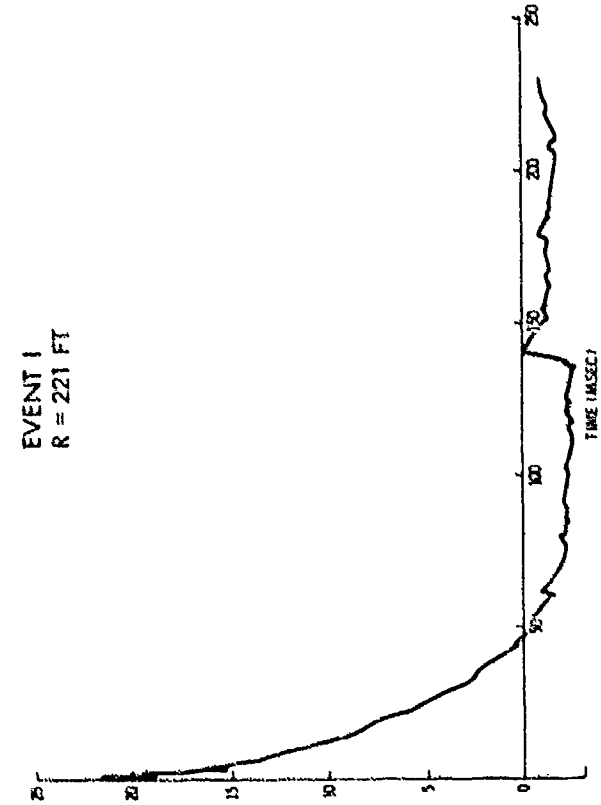

EVENT I
R = 80.1 FT
SIDE-ON OVERPRESSURE (PSI)

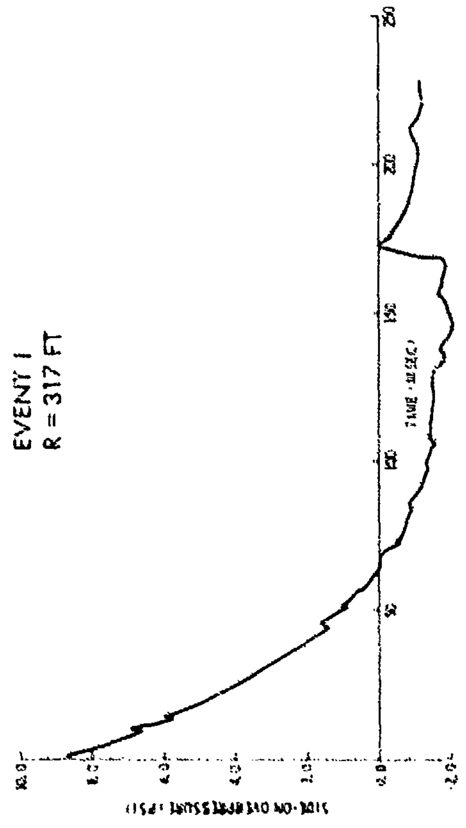

EVENT I
R = 107 FT
TIME (MSEC)
SIDE-ON OVERPRESSURE (PSI)

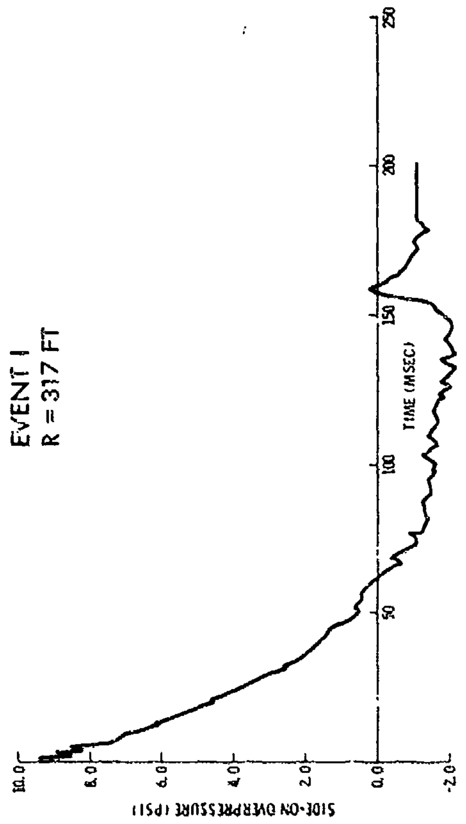

EVENT I
R = 146 FT
SIDE-ON OVERPRESSURE (PSI)
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
TIME (MSEC)
10.0
20.0
30.0
40.0
50.0
60.0

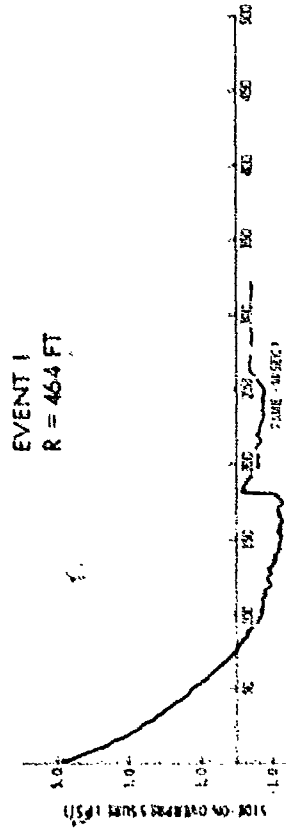

EVENT I
R = 221 FT
SIDE-ON OVERPRESSURE (PSI)
25
20
15
10
5
0
-5
TIME (MSEC)
50
100
150
200
250

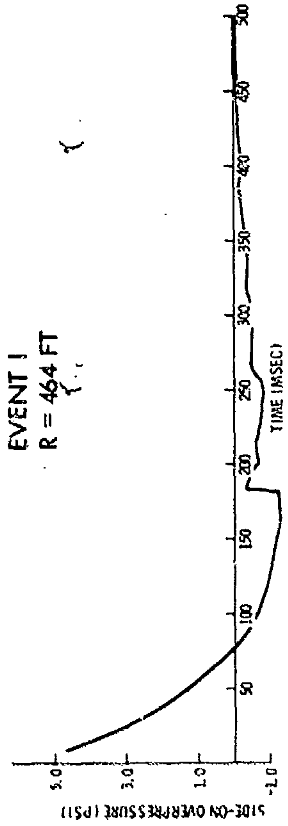

EVENT I
R = 146 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)

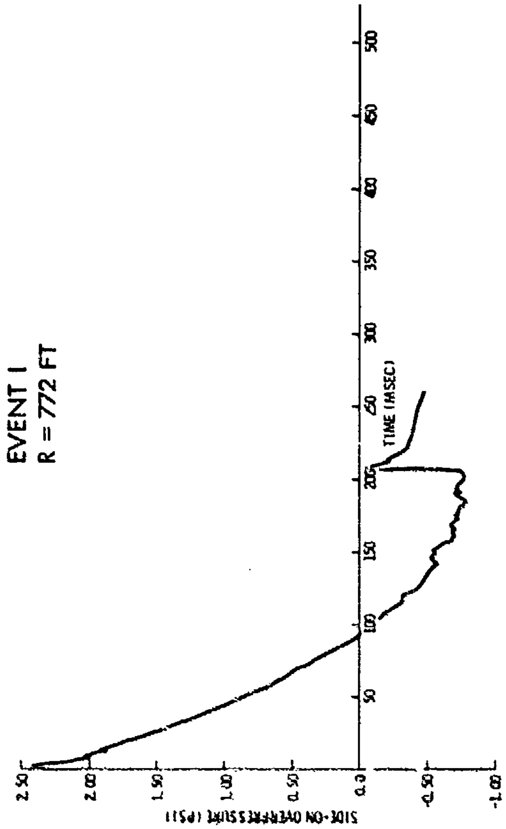

EVENT I
R = 221 FT
SIDE-ON OVERPRESSURE (PSI)
25
20
15
10
5
0
TIME (MSEC)
50
100
150
200
250

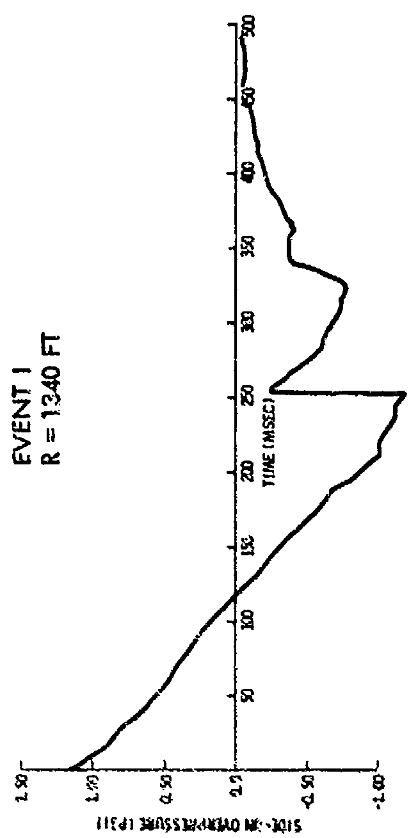

EVENT I
R = 317 FT
SIDE-ON OVERPRESSURE (PSI)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
50
100
150
200
250

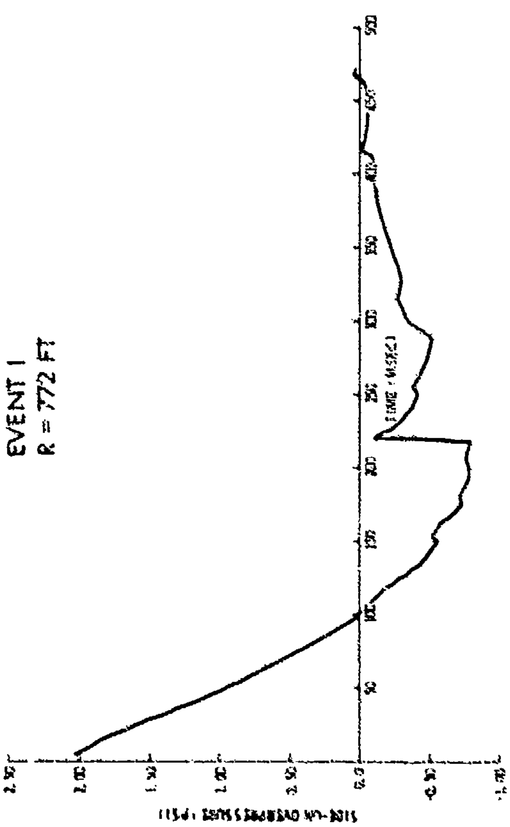

EVENT I
R = 317 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
50
100
150
200
250

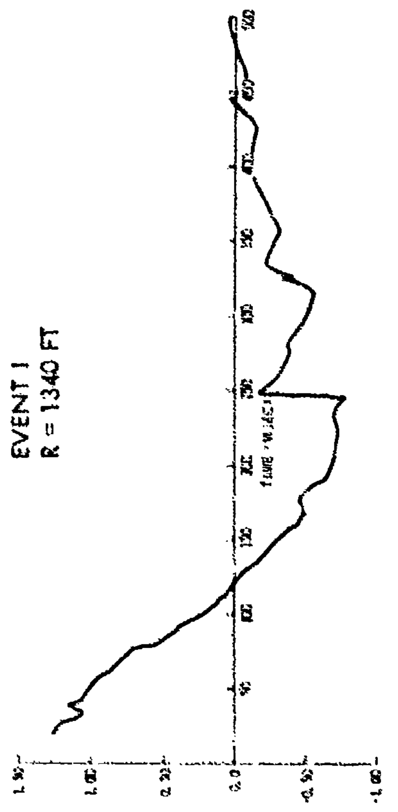

EVENT I
R = 464 FT
SIDE-ON OVERPRESSURE (PSI)
50
100
150
200
250
300
350
400
450
500

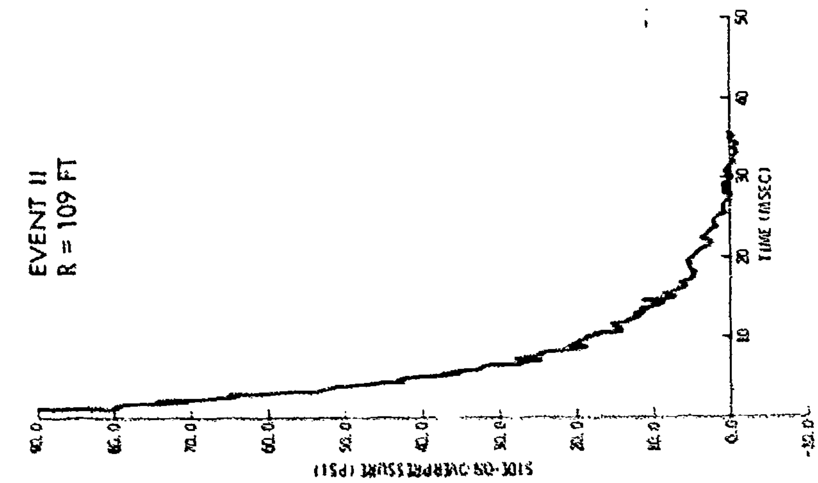

EVENT I
R = 464 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)
5.0
3.0
1.0
-1.0
50
100
150
200
250
300
350
400
450
500

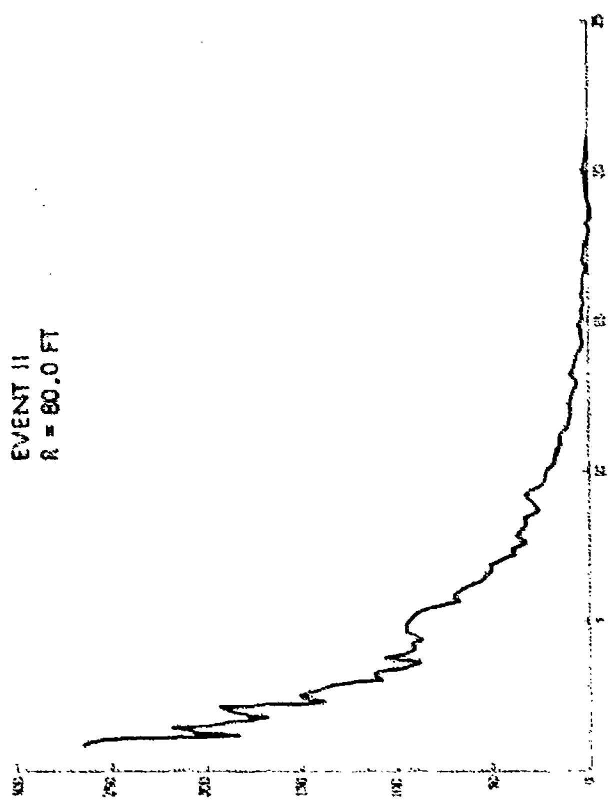

EVENT I
R = 772 FT
TIME (MSEC)
SIDE-ON OVERPRESSURE (PSI)

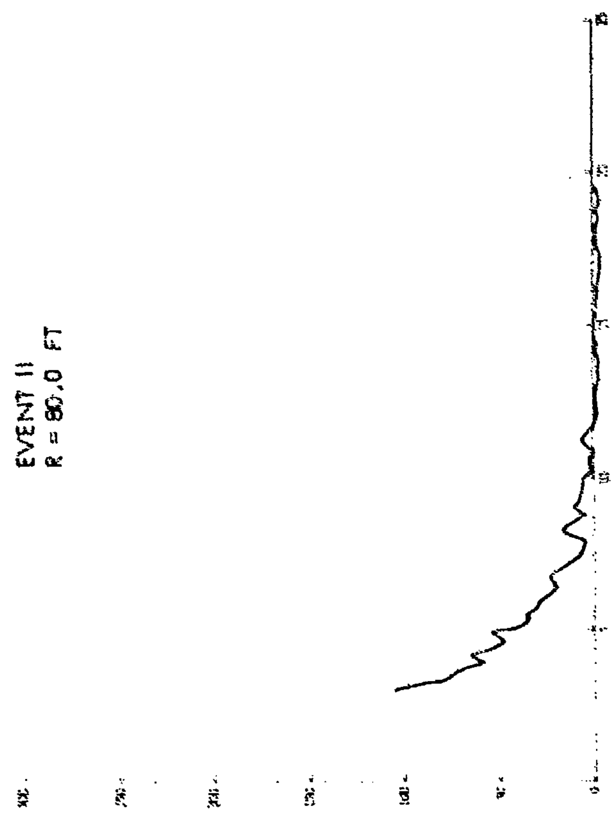

EVENT I
R = 1340 FT
TIME (MSEC)

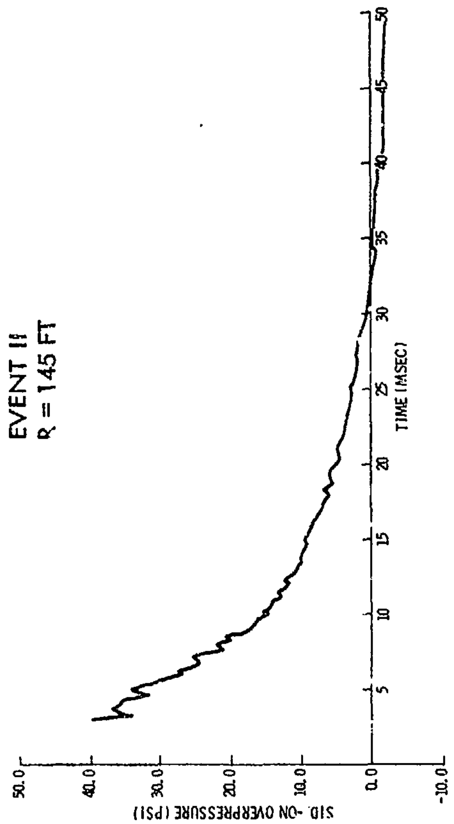

EVENT I
R = 772 FT

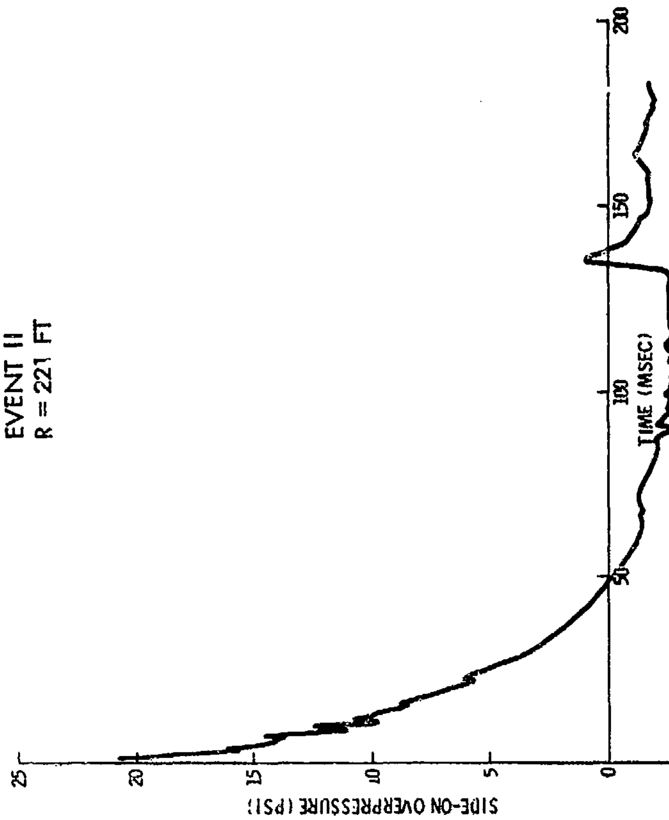

EVENT I
R = 1340 FT

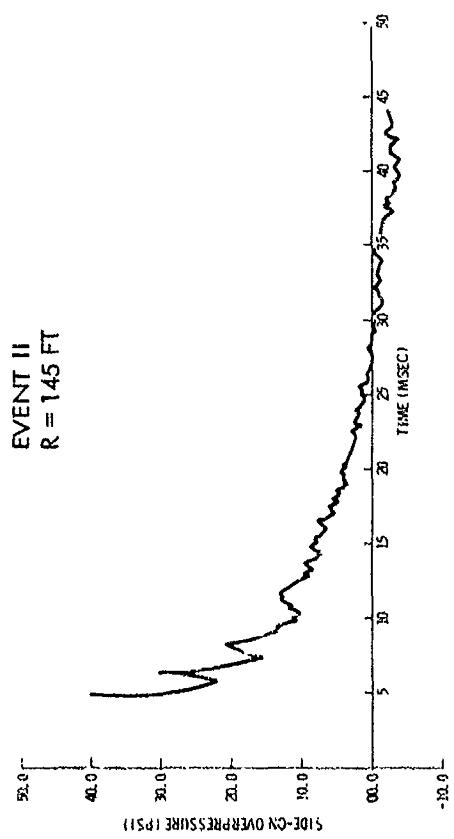

EVENT II
R = 109 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)

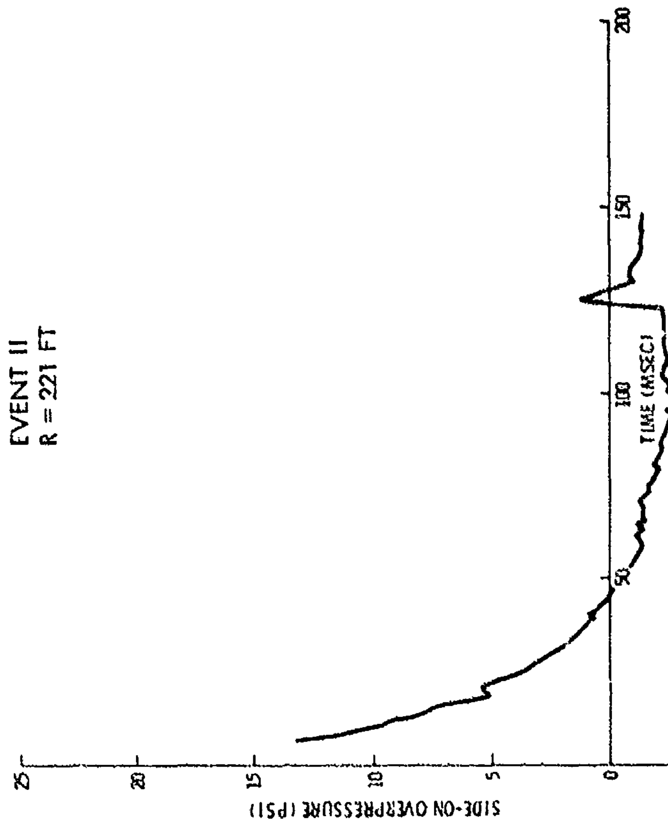

EVENT II
R = 80.0 FT

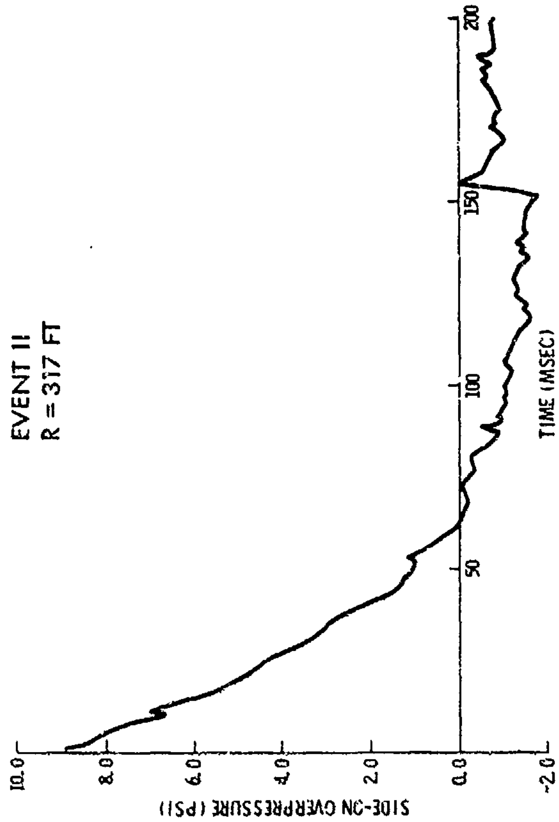

EVENT II
R = 80.0 FT

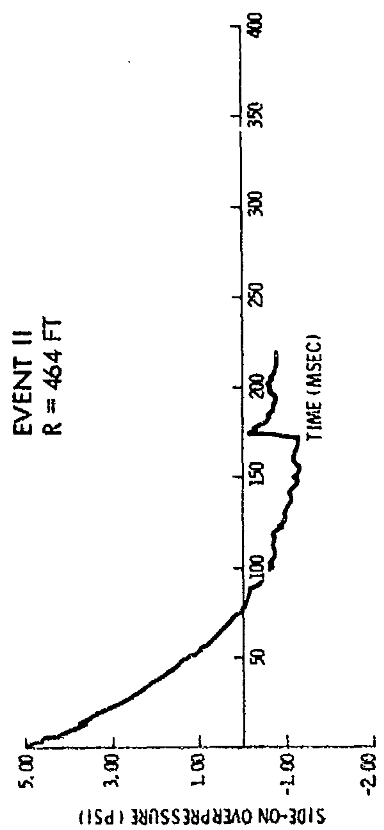

EVENT II
R = 145 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)

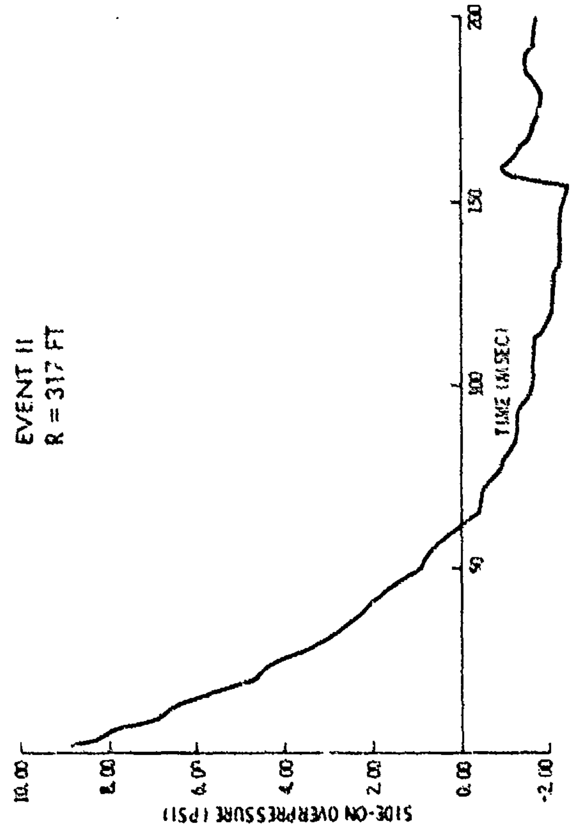

EVENT II
R = 221 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)

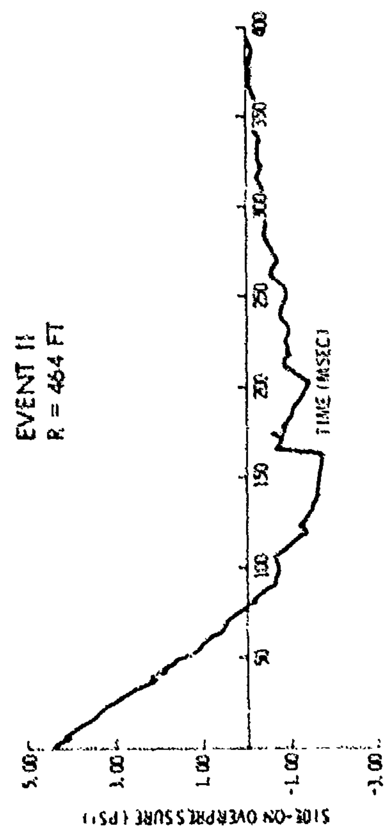

EVENT II
R = 145 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)

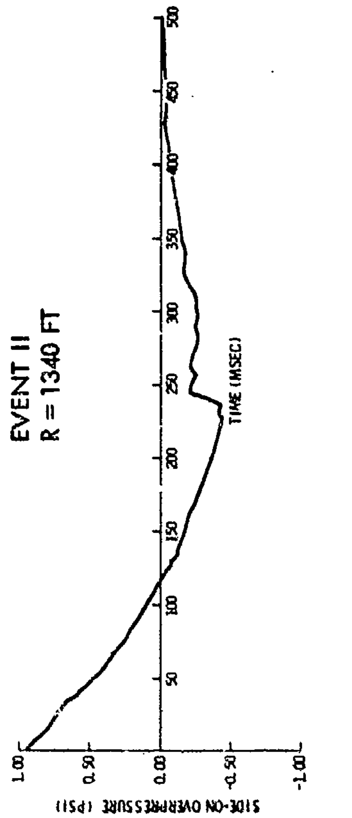

EVENT II
R = 221 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)

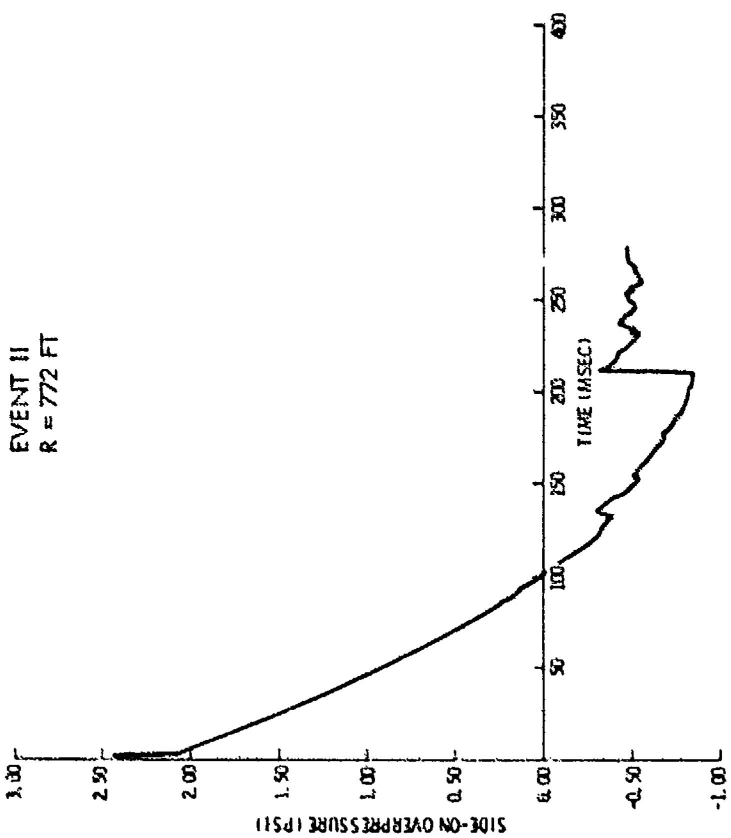

EVENT II
R = 317 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
50
100
150
200

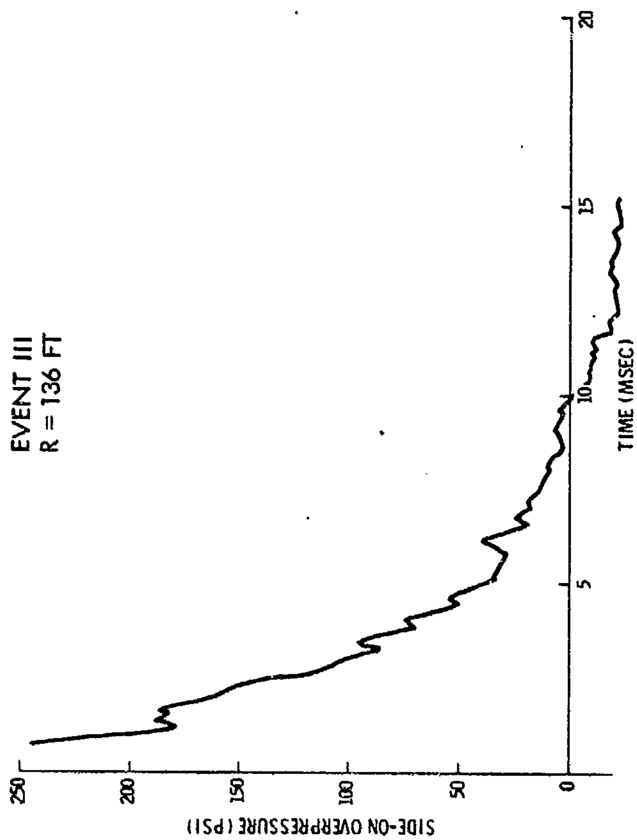

EVENT II
R = 464 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)
5.00
3.00
1.00
-1.00
-2.00
50
100
150
200
250
300
350
400

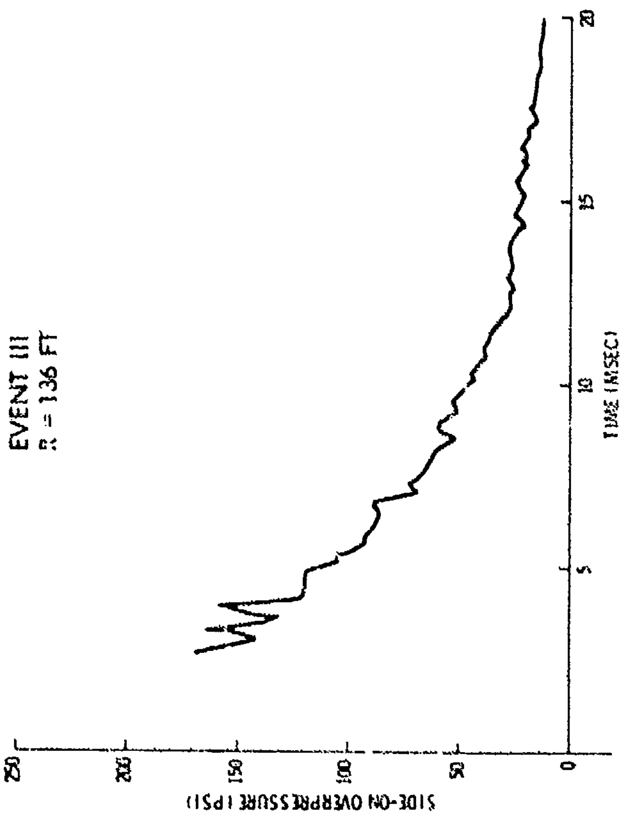

EVENT II
R = 317 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
50
100
150
200

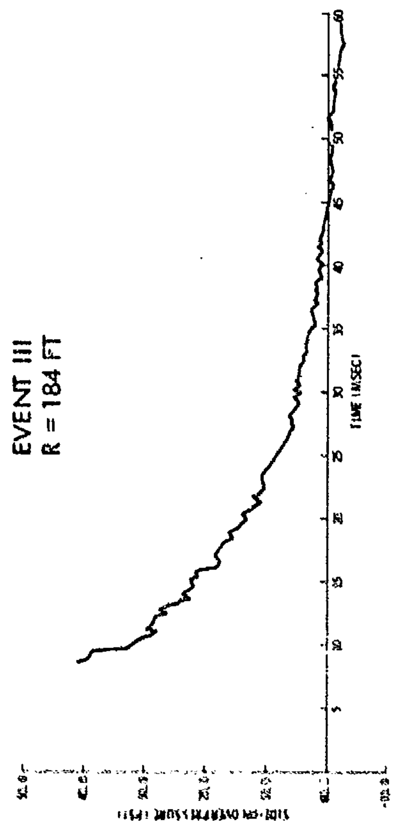

EVENT II
R = 464 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)
5.00
3.00
1.00
-1.00
-3.00
50
100
150
200
250
300
350
400

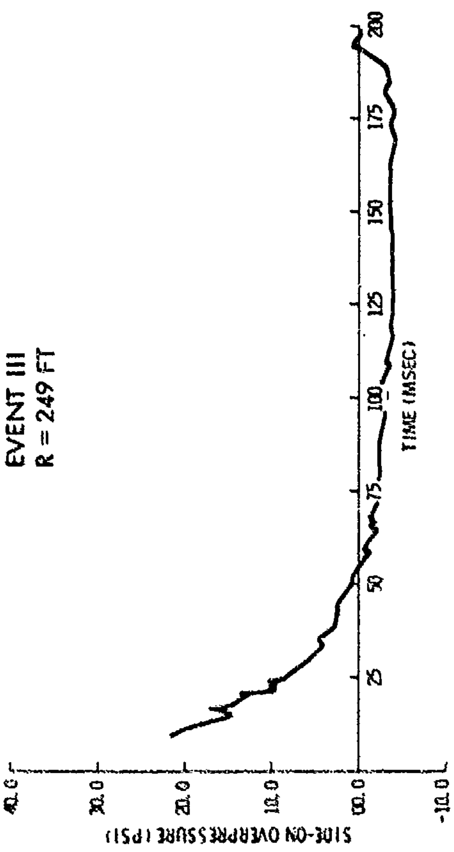

EVENT II
R = 1340 FT
SIDE-ON OVERPRESSURE (PSI)
1.00
0.50
0.00
-0.50
-1.00
TIME (MSEC)
50
100
150
200
250
300
350
400
450
500

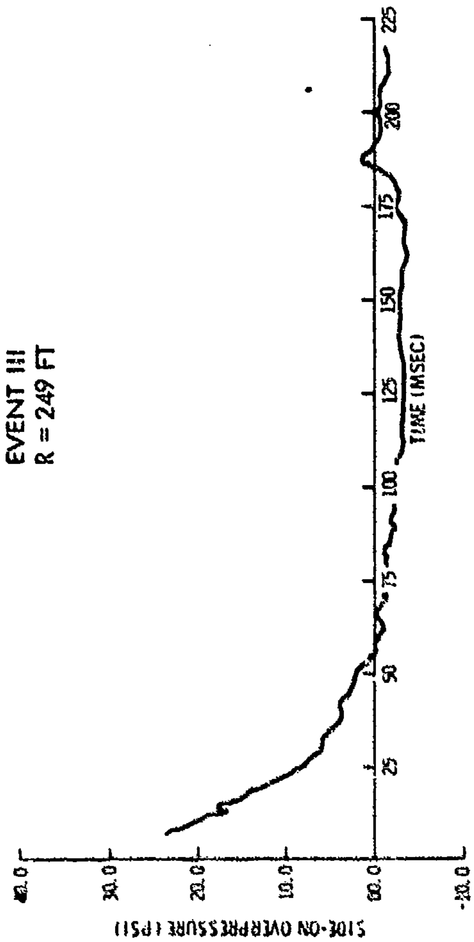

EVENT II
R = 772 FT
SIDE-ON OVERPRESSURE (PSI)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
TIME (MSEC)
50
100
150
200
250
300
350
400

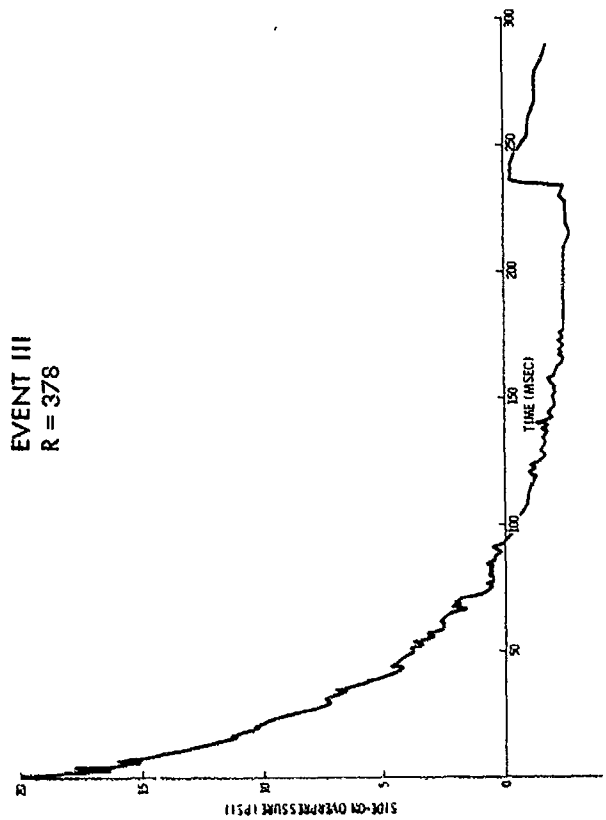

EVENT III
R = 136 FT
TIME (MSEC)
SIDE-ON OVERPRESSURE (PSI)

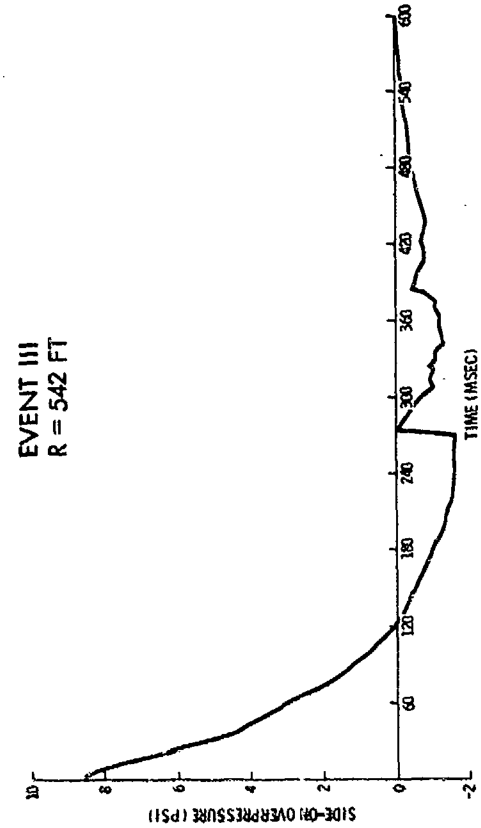

EVENT III
R = 136 FT
TIME (MSEC)
SIDE-ON OVERPRESSURE (PSI)

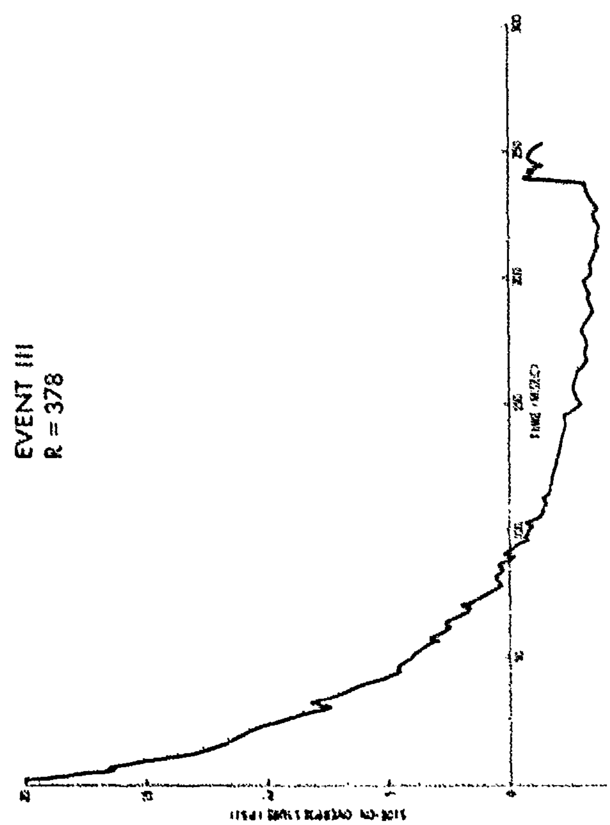

EVENT III
R = 184 FT

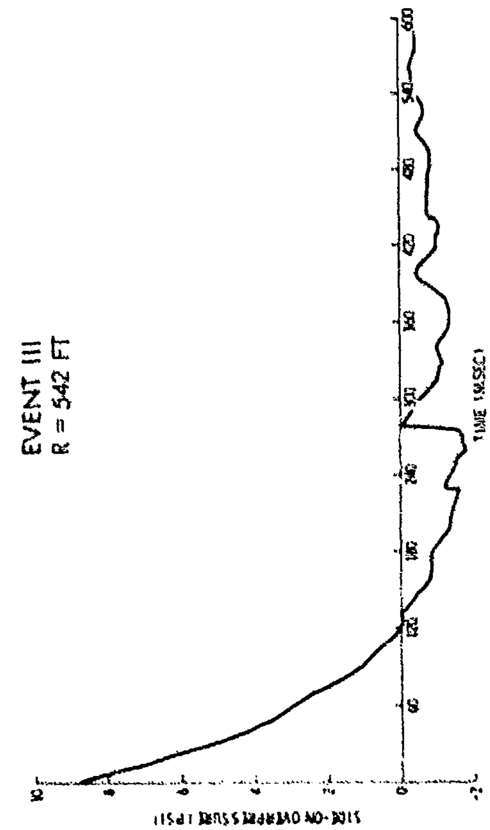

EVENT III
R = 249 FT
SIDE-ON OVERPRESSURE (PSI)
40.0
30.0
20.0
10.0
00.0
-10.0
TIME (MSEC)
25
50
75
100
125
150
175
200

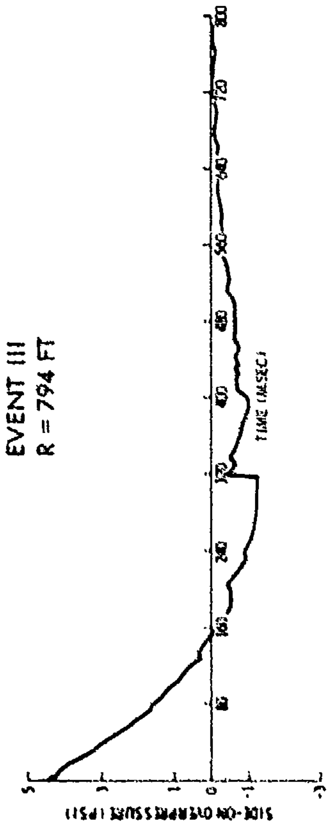

EVENT III
R = 249 FT
SIDE-ON OVERPRESSURE (PSI)
40.0
30.0
20.0
10.0
00.0
-10.0
TIME (MSEC)
25
50
75
100
125
150
175
200
225

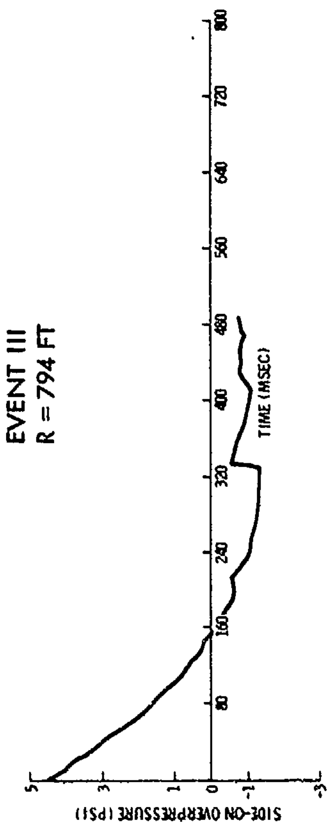

EVENT III
R = 378
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)


EVENT III
R = 542 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)


EVENT III
R = 378


EVENT III
R = 542 FT


EVENT III
R = 794 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)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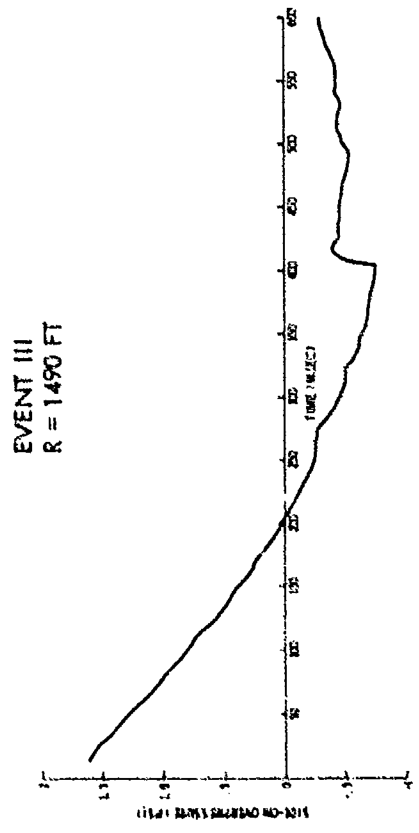
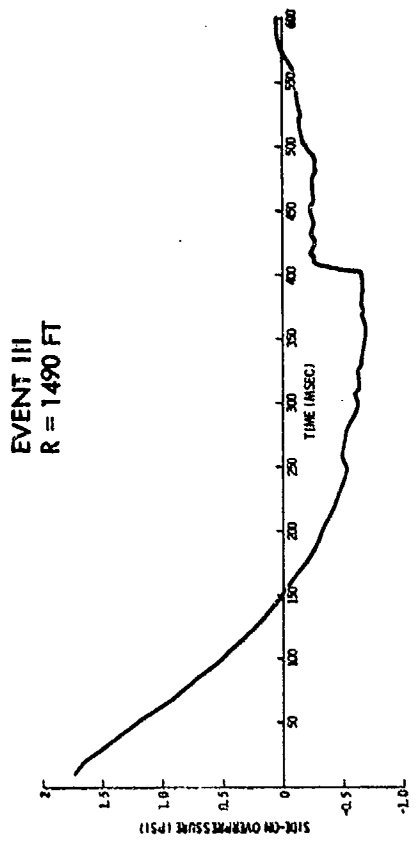
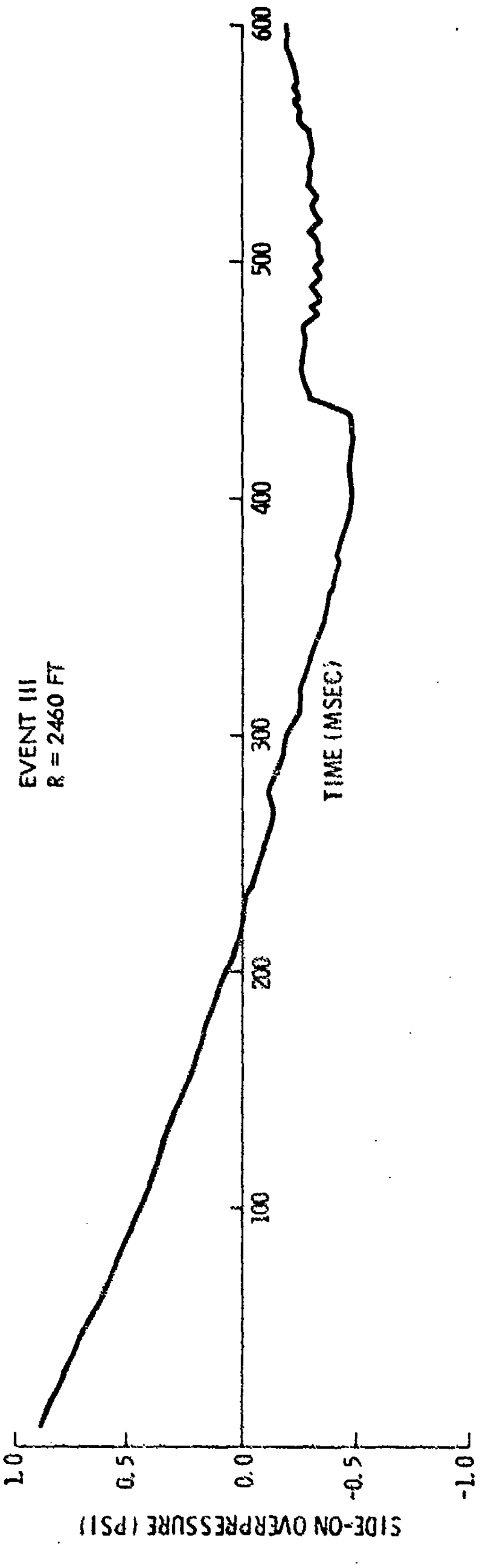
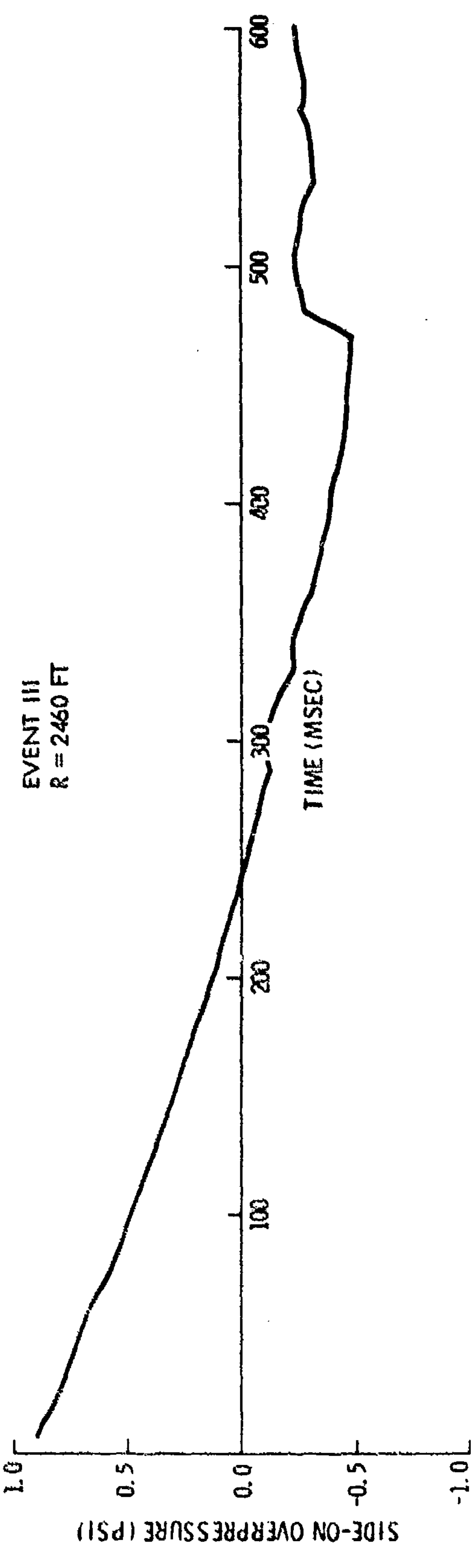
R = 794 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)


EVENT III
R = 1490 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)


EVENT III
R = 1490 FT
SIDE-ON OVERPRESSURE (PSI)
TIME (MSEC)


EVENT III
R = 2460 FT
TIME (MSEC)
SIDE-ON OVERPRESSURE (PSI)
1.0
0.5
0.0
-0.5
-1.0
100
200
300
400
500
600


EVENT III
R = 2460 FT
TIME (MSEC)
SIDE-ON OVERPRESSURE (PSI)
1.0
0.5
0.0
-0.5
-1.0
100
200
300
400
500
600

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University of California
P. O. Box 808
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Albuquerque, New Mexico 87100 Attn: Dr. D. Richmond

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Urbana, Illinois 61803
Attn: Dr. N. Newmark

University of Michigan
Institute of Science and Technology
P. O. Box 618
Ann Arbor, Michigan 48104
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Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, Massachusetts 02139
Attn: Dr. R. Hansen

St. Louis University
221 North Grand
St. Louis, Missouri 63100
Attn: Dr. C. Kisslinger

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13. ABSTRACT Two twenty-ton and one 100-ton hemispherical AN/FO (ammonium nitrate/fuel oil) charges were detonated on the surface at the Defence Research Establishment, Suffield, Ralston, Alberta, Canada. The tests were conducted during August 1969 as a cooperative U. S./Canadian effort.

The major results were:

1. AN/FO has been demonstrated to be a highly suitable explosion source for nuclear airblast simulation.

2. Over the 1-200 psi region, there was no significant difference in the pressure-distance characteristics between AN/FO and TNT.

3. The impulse characteristics of the AN/FO system were found to be slightly lower than those of TNT.

4. No self heating of AN/FO was observed.

5. Conventional cube root scaling applies for AN/FO over a 10^3 range in explosive weight, once a charge weight of 200 pounds is exceeded.

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Airblast						
Explosive						
Ammonium Nitrate/Fuel Oil						
Thermal Stability						
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Instrumentation						
Hemispherical Charges						